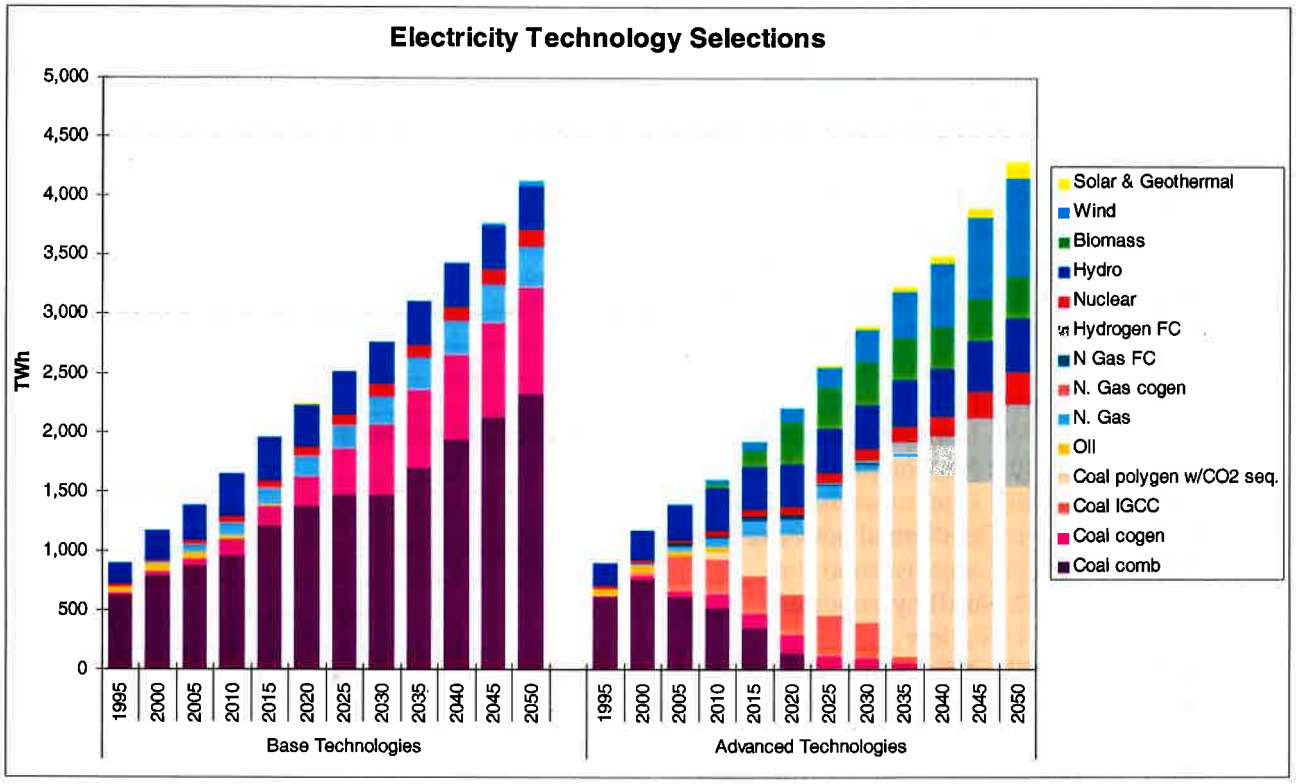
# Conversion and Process Technology Data For China MARKAL Model, 1995-2050

## APPENDIX B to
## *Future Implications of China's Energy-Technology Choices*




**Prepared for the**
**Working Group on Energy Strategies and Technologies (WGEST)**
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## INTRODUCTION

This appendix provides detailed information regarding the source of input parameter values for all technologies for converting primary energy into secondary energy carriers, including electricity, heat, liquid fuels, and gaseous fuels. Beginning on the following page, the numerical input values for each of the 71 energy conversion technologies included in the model are given in tabular form. These tables are followed by descriptions of the sources of the tabulated values. The technology parameters shown in the tables that begin on the next page are defined as follows:

| Parameter Name and [MARKAL Variable] | Units and notes |
|---|---|
| Annual capacity utilization [CF] | % annual capacity utilization. |
| Availability Factor [AF] | % annual capacity utilization (for technologies that generate or co-generate electricity). |
| Carbon sequestered [OUT(MAT)c] | $10^3$ $tCO_2$ / PJ of energy input for technologies that generate or co-generate electricity. |
| Carbon sequestered [OUT(MAT)p] | $10^3$ $tCO_2$ / PJ of energy input for technologies that generate or co-generate electricity. |
| Energy carrier output [OUT(ENC)c] | GJ energy carrier out per GJ electricity out (for electricity producing technologies). |
| Energy carrier output [OUT(ENC)p] | For processes producing more than one energy carrier (but no electricity), fraction of all energy carriers produced (GJ) that is accounted for by a particular carrier. For the oil refinery, these represent maximum fractions – the model calculates the actual fractions. |
| First year technology is available [START] | First year that this technology can be selected for use by the model. |
| Fixed O&M [FIXOM] | $/kW-yr. Defined only for technologies that generate or co-generate electricity. |
| Fraction of capacity available at peak [PEAK(CON)] | For electricity generating technologies, amount of the installed capacity available to meet peak electricity demand. Unless indicated otherwise, the value of PEAK(CON) is one. |
| $H_2$ trans./distr. cost [DELIV(ENT)] | $/GJ of $H_2$ for delivery from production site to point of use. |
| Input energy [INP(ENT)c] | GJ energy in per GJ electricity output (for technologies that generate electricity). |
| Input energy [INP(ENT)p] | GJ energy in/GJ energy carriers produced (for technologies that generate no electricity). |
| Investment cost [INVCOST] | $/kW of installed electrical capacity (for technologies that generate electricity); $/GJ/yr of energy carrier produced (for technologies that don't generate electricity). |
| Maximum capacity allowed [BOUND(BD), HI] | Maximum allowed total installed capacity. Units are GW for electricity generating technologies and GJ/yr for non-electric technologies. |
| Maximum capacity growth [GROWTH] | Maximum allowed annual % growth in installed capacity. |
| Maximum production [BOUND(BD)O, HI] | Maximum annual production (PJ/year) of electricity or other energy carrier. |
| Minimum capacity installed [BOUND(BD), LO] | Minimum required installed capacity. Units are GW for electricity generating technologies and GJ/yr for non-electric technologies. |
| Minimum production [BOUND(BD)O, LO] | Minimum amount of production (PJ/year) required of electricity or other energy carrier. |
| Plant operating lifetime [LIFE] | Number of years that a technology is available for operation. |
| Ratio of electricity-to-heat out [REH] | PJ per PJ, for technologies co-generating heat and electricity. |
| Residual capacity [RESID] | Existing capacity at start of simulation. (This capacity must be manually phased out by the user, since Markal will otherwise assume it is new capacity.) |
| SO2 Emissions [ENV_ACT, SO2] | $10^3$ $tSO_2$ / PJ of output electricity or (for non-electric technologies) other energy carrier. |
| Utilization factor for season-time of day [CF(Z)(Y)] | Fraction of installed capacity utilized during different seasons: I = intermediate, S = summer, W = winter; and during day (D) or night (N). |
| Variable O&M [VAROM] | $ per kWh generated (for technologies that generate or co-generate electricity). $/GJ of all energy carriers produced (for technologies that generate other than electricity). |

## GENERAL NOTES ON PARAMETER VALUES

1. The lower heating value is used for all fuels.
2. For all technologies, we have not adjusted capital investment estimates from the literature for different physical locations (e.g., China versus the USA). Costs for installing a technology in one physical location may be higher or lower than in another. For example, Stoll and Todd (1996) show a capital investment multiplier of 0.65 on US Gulf Coast costs for an IGCC installation to estimate the cost of the installation in China. Yang (1995) carried out a detailed cost comparison for IGCC in the USA and in China and estimated the multiplier to be in the range from 0.47 to 0.55.
3. The model assumes that all investment costs are for $N^{th}$ plants, i.e., technologies are introduced in China once they have reached commercially mature cost levels. For most of the technologies, no performance improvements or cost reductions over time are assumed.
4. For technologies where $CO_2$ capture is included, we use cost estimates for capture from the original literature sources wherever possible. For some technologies, the literature source gives the rate at which $CO_2$ could potentially be captured, but capture costs are not explicitly estimated. In these cases, we assume a capital cost of \$628 per $m^3CO_2$/hour for capture of $CO_2$ based on an estimate in David and Herzog (2000) (IGCC 2012 case). David and Herzog also give an added variable O&M cost for $CO_2$ capture of \$0.005 per $m^3CO_2$. (We assume in all cases that annual O&M costs are 4% of initial capital investment.) The capture costs derived from David and Herzog are consistent with the lower end of the range (\$0.5 to \$0.77 per thousand standard $ft^3$ $CO_2$ captured) given by Wong *et al.* (2000).
5. For all technologies involving carbon capture and sequestration, the cost of transporting and sequestrating pressurized $CO_2$ (~100 bar) is assumed to be \$5 per metric tonne of $CO_2$ sequestered (if not given explicitly in the cited sources), the cost estimate given by Williams (2000) in notes to Table 8.9. (The cost of $CO_2$ compression is included as part of the conversion facility capital cost.) The transport and sequestration cost is converted into a capital cost equivalent and included as part of the overall capital cost for the technology. For example, Williams (2000, Table 8.9) indicates that for a 400 MW IGCC plant, the $CO_2$ capture rate is 210 gC/kWh (770 $gCO_2$/kWh). The capital cost equivalent (\$/$kW_e$) for transport and sequestration for this plant would be

$$5\ \$/tCO_2 * (770*10^{-6}\ tCO_2/kWh) * (8760\ h/yr *CF)/CCR$$

   where CF is the plant capacity factor and CCR is the assumed capital charge rate. Assuming CF = 0.8 and CCR = 0.15, the capital cost equivalent is \$225/$kW_e$. This compares with a capital cost of \$1514/$kW_e$ indicated by Williams for an IGCC plant that includes $CO_2$ capture and compression.
6. Cost estimates are given in mid-1990s US dollars. For cost estimates using dollar-years earlier than the mid-1990s, corrections based on US GDP deflator are applied to bring the estimates to mid-1990s dollars. Where corrections have been made, the specific values used are indicated in the technology notes below. No corrections are applied to original estimates given in mid-1990s or later dollars.
7. The plant availability (AF in Markal) is assumed to be 85% for all conversion and process technologies using solid fuels (plus nuclear and geothermal) and 90% for all technologies using gas or liquid fuels. Exceptions to these are values for hydro (50%) and for solar and wind (fixed-capacity utilization technologies).

# TABULATED PARAMETER VALUES

## BASE SCENARIOS

### ELECTRICITY TECHNOLOGIES (GENERATING ELECTRICITY OR ELECTRICITY AND CO-PRODUCTS)

| | | | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | **Biomass, gasifier co-production of gas and IC-engine electricity, village scale (EBV01)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 | 128.7 |
| | Input energy [INP(ENT)c] | | | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 | 14.99 |
| | Investment cost (INVCOST) | | | 4,336.00 | 3,686.00 | 3,133.00 | 2,819.00 | 2,819.00 | 2,819.00 | 2,819.00 | 2,819.00 | 2,819.00 | 2,819.00 | 2,819.00 |
| | Energy carrier output [OUT(ENC)c] | | | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 | 3.84 |
| | Variable O&M (VAROM) | | | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 | 8.7 |
| | Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| | First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **B2** | **Coal, steam-cycle electricity at < 100 MW (EC01)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 | 3.899 |
| | Fixed O&M (FIXOM) | | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 | 20.28 |
| | Input energy [INP(ENT)c] | | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 | 3.77 |
| | Investment cost (INVCOST) | | 676 | 676 | 676 | 676 | 676 | 676 | 676 | 676 | 676 | 676 | 676 | 676 |
| | Residual capacity (RESID) | | 31 | 15.5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable O&M (VAROM) | | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 |
| | Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| | First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B3** | **Coal, steam-cycle electricity at 100 to 200 MW (EC02)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 | 3.625 |
| | Fixed O&M (FIXOM) | | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 |
| | Input energy [INP(ENT)c] | | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 |
| | Investment cost (INVCOST) | | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 | 650 |
| | Residual capacity (RESID) | | 25.55 | 20 | 15 | 10 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable O&M (VAROM) | | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 | 1.112 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B4** | **Coal, steam-cycle electricity at 200 to 300 MW (EC03)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 |
| | Fixed O&M (FIXOM) | | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 | 18.75 |
| | Maximum capacity growth (GROWTH) | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Input energy [INP(ENT)c] | | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 |
| | Investment cost (INVCOST) | | 625 | 625 | 625 | 625 | 625 | 625 | 625 | 625 | 625 | 625 | 625 | 625 |
| | Residual capacity (RESID) | | 36.6 | 30 | 24 | 18 | 12 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable O&M (VAROM) | | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B5** | **Coal, steam-cycle electricity at > 300 MW, with ESP (EC04)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 | 3.038 |
| | Fixed O&M (FIXOM) | | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| | Maximum capacity growth (GROWTH) | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Input energy [INP(ENT)c] | | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 | 2.94 |
| | Investment cost (INVCOST) | | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| | Residual capacity (RESID) | | 43.26 | 35.8 | 28.6 | 21.4 | 14.7 | 7 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable O&M (VAROM) | | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 | 0.973 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B6** | **Coal, steam-cycle electricity at > 300 MW, with ESP and dry FGD (EC05)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 | 1.252 |
| | Fixed O&M (FIXOM) | | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 | 23.75 |
| | Input energy [INP(ENT)c] | | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 |
| | Investment cost (INVCOST) | | 709 | 709 | 709 | 709 | 709 | 709 | 709 | 709 | 709 | 709 | 709 | 709 |
| | Residual capacity (RESID) | | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Variable O&M (VAROM) | | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B7** | **Coal, steam-cycle electricity at > 300 MW, with ESP and dry FGD (EC06)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 |
| | Fixed O&M (FIXOM) | | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 |
| | Input energy [INP(ENT)c] | | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 |
| | Investment cost (INVCOST) | | 764 | 764 | 764 | 764 | 764 | 764 | 764 | 764 | 764 | 764 | 764 | 764 |
| | Variable O&M (VAROM) | | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **B8** | **Coal, steam-cycle electricity at > 300 MW, with ESP and combined SOx, NOx (EC07)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 | 0.313 |
| | Fixed O&M (FIXOM) | | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 | 28.75 |
| | Input energy [INP(ENT)c] | | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 |
| | Investment cost (INVCOST) | | 788 | 788 | 788 | 788 | 788 | 788 | 788 | 788 | 788 | 788 | 788 | 788 |
| | Variable O&M (VAROM) | | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 |

**B9 Coal, steam-cycle, pulverized coal at 500 MW, with FGD (EC08)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 |
| Fixed O&M (FIXOM) | | | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 |
| Maximum capacity growth (GROWTH) | | | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 | 1.05 |
| Input energy [INP(ENT)c] | | | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 | 2.74 |
| Investment cost (INVCOST) | | | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 | 1,090.00 |
| Variable O&M (VAROM) | | | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B10 Coal, steam-cycle, atmospheric-pressure fluidized-bed combustion (EC09)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 |
| Fixed O&M (FIXOM) | | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 | 27 |
| Input energy [INP(ENT)c] | | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 | 2.7 |
| Investment cost (INVCOST) | | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 | 900 |
| Variable O&M (VAROM) | | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 | 2.363 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B11 Coal, steam-cycle, pressurized fluidized-bed combustion (EC0A)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 | 0.456 |
| Fixed O&M (FIXOM) | | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 | 33.75 |
| Input energy [INP(ENT)c] | | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 | 2.38 |
| Investment cost (INVCOST) | | 1,327.00 | 1,327.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 | 1,025.00 |
| Variable O&M (VAROM) | | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 | 1.251 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B12 Coal, steam-cycle, ultrasupercritical (EC0B)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum capacity allowed [BOUND(BD)] | | | | 5 | | | | | | | | | |
| SO2 Emissions | | | | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 |
| Fixed O&M (FIXOM) | | | | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 |
| Maximum capacity growth (GROWTH) | | | | 1.3 | 1.3 | 1.25 | 1.25 | 1.2 | 1.2 | 1.15 | 1.15 | 1.1 | 1.1 |
| Input energy [INP(ENT)c] | | | | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 |
| Investment cost (INVCOST) | | | | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 |
| Variable O&M (VAROM) | | | | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | | |

**B13 Coal, steam-cycle cogeneration of electricity and low-temperature district heating (ECG01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 | 3.026 |
| Fixed O&M (FIXOM) | | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| Input energy [INP(ENT)c] | | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 | 2.93 |
| Investment cost (INVCOST) | | 721 | 721 | 721 | 721 | 721 | 721 | 721 | 721 | 721 | 721 | 721 | 721 |
| Ratio of electricity-to-heat out (REH) | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Residual capacity (RESID) | | 17 | 12.75 | 8.5 | 4.25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B14 Coal, steam-cycle, cogeneration of electricity and high-temperature process heat (ECG02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum capacity allowed [BOUND(BD)] | | | 1 | | | | | | | | | | |
| SO2 Emissions | | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 | 0.1474 |
| Fixed O&M (FIXOM) | | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 | 19.89 |
| Maximum capacity growth (GROWTH) | | | 1.3 | 1.2 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| Input energy [INP(ENT)c] | | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 | 3.16 |
| Investment cost (INVCOST) | | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 995 | 995 |
| Energy carrier output [OUT(ENC)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable O&M (VAROM) | | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 | 0.79 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B15 Coal, new, cleaner steam-cycle cogeneration of electricity and low-temperature district heating (ECG04)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 | 0.1278 |
| Fixed O&M (FIXOM) | | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 | 36 |
| Input energy [INP(ENT)c] | | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 |
| Investment cost (INVCOST) | | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 | 750 |
| Ratio of electricity-to-heat out (REH) | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Variable O&M (VAROM) | | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 | 3.36 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B16 Coal, heating plant, large scale (ECH01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 | 1.435 |
| Fixed O&M (FIXOM) | | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Input energy [INP(ENT)c] | | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 |
| Investment cost (INVCOST) | | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 | 115 |
| Residual capacity (RESID) | | 19 | 14.25 | 9.5 | 4.75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B17 Coal heating plant, advanced boiler (ECH02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 | 0.052 |
| Fixed O&M (FIXOM) | | | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 | 9.9 |
| Input energy [INP(ENT)c] | | | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 |
| Investment cost (INVCOST) | | | 493 | 493 | 493 | 493 | 493 | 493 | 493 | 493 | 493 | 493 | 493 |
| Variable O&M (VAROM) | | | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B18 Geothermal, steam-cycle electricity production (EG01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum capacity allowed [BOUND(BD)] | | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 | 0.1 | 0.12 | 0.14 | 0.15 | 0.16 | 0.17 | 0.18 |
| Fixed O&M (FIXOM) | | 30 | 28.5 | 27 | 25.8 | 24.5 | 23.3 | 22 | 22 | 22 | 22 | 22 | 22 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 2,000.00 | 1,902.00 | 1,809.00 | 1,720.00 | 1,636.00 | 1,556.00 | 1,479.00 | 1,479.00 | 1,479.00 | 1,479.00 | 1,479.00 | 1,479.00 |
| Residual capacity (RESID) | | 0.0288 | 0.0288 | 0.0288 | 0.0144 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 | 0.014 |
| Plant operating lifetime [LIFE] | 15 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B19 Hydroelectric power, large (> 25 MW) (EH01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Required minimum capacity installed [BOUND(BD)] | | 36.52 | 54.35 | 69.35 | 87.35 | 87.35 | 87.35 | 87.35 | 87.35 | 87.35 | 87.35 | 87.35 | 87.35 |
| Maximum capacity allowed [BOUND(BD)] | | 38 | 57 | 72 | 90 | 115 | 140 | 170 | 200 | 225 | 250 | 275 | 300 |
| Fixed O&M (FIXOM) | | 13 | 13 | 14 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 | 15 |
| Maximum capacity growth (GROWTH) | | | | | 1.05 | 1.04 | 1.02 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 1,300.00 | 1,300.00 | 1,400.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 | 1,500.00 |
| Residual capacity (RESID) | | 36.52 | 31.955 | 27.39 | 22.825 | 18.26 | 13.695 | 9.13 | 4.565 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 |
| Plant operating lifetime [LIFE] | 40 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B20 Hydroelectric power, small (< 25 MW) (EH02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| Required minimum capacity installed [BOUND(BD)] | | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 | 15.65 |
| Maximum capacity allowed [BOUND(BD)] | | 17 | 18 | 20 | 23 | 26 | 30 | 35 | 40 | 46 | 52 | 58 | 65 |
| Fixed O&M (FIXOM) | | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 | 19.5 |
| Maximum capacity growth (GROWTH) | | | | | 1.05 | 1.04 | 1.02 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 | 1.01 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 | 1,300.00 |
| Residual capacity (RESID) | | 15.65 | 13.6938 | 11.7375 | 9.7813 | 7.825 | 5.8688 | 3.9125 | 1.9563 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 | 0.278 |
| Plant operating lifetime [LIFE] | 40 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B21 Nuclear electricity (EN01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Required minimum capacity installed [BOUND(BD)] | | 2.1 | | | | | | | | | | | |
| Maximum capacity allowed [BOUND(BD)] | | | 10 | 19.25 | 30 | 45 | 60 | 80 | 100 | 125 | 150 | 180 | 216 |
| Fixed O&M (FIXOM) | | 50 | 50 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 | 40 |
| Input energy [INP(ENT)c] | | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 | 3.03 |
| Investment cost (INVCOST) | | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 | 2,000.00 |
| Residual capacity (RESID) | | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 | 2.4 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B22 Natural gas, simple-cycle gas turbine peaking electricity generation (ENG01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Fixed O&M (FIXOM) | | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Input energy [INP(ENT)c] | | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Investment cost (INVCOST) | | 543 | 543 | 543 | 543 | 543 | 543 | 543 | 543 | 543 | 543 | 543 | 543 |
| Residual capacity (RESID) | | 0.23 | 0.23 | 0.23 | 0.23 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 | 2.224 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B23 Natural gas, gas turbine combined cycle electricity production (ENG02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Fixed O&M (FIXOM) | | | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 | 16.1 |
| Input energy [INP(ENT)c] | | | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| Investment cost (INVCOST) | | | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Variable O&M (VAROM) | | | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 | 0.42 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

**B24 Natural gas, gas turbine combined cycle cogeneration of electricity and high-temperature process heat (ENG04)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Fixed O&M (FIXOM) | | | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 | 9.7 |
| Input energy [INP(ENT)c] | | | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 | 2.18 |
| Investment cost (INVCOST) | | | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 | 640 |
| Energy carrier output [OUT(ENC)c], heat | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable O&M (VAROM) | | | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 | 0.38 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | | |

**B25 Oil, steam-cycle, electricity production (EO01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| SO2 Emissions | | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 | 0.417 |
| Fixed O&M (FIXOM) | | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 | 15.9 |
| Input energy [INP(ENT)c] | | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 | 2.86 |
| Investment cost (INVCOST) | | 530 | 530 | 530 | 530 | 530 | 530 | 530 | 530 | 530 | 530 | 530 | 530 |
| Residual capacity (RESID) | | 5.38 | 2.69 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B26 Oil, gas turbine combined-cycle, electricity production (EO02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| SO2 Emissions | | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 | 0.275 |
| Fixed O&M (FIXOM) | | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Input energy [INP(ENT)c] | | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 | 2.5 |
| Investment cost (INVCOST) | | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 | 600 |
| Residual capacity (RESID) | | 3.1 | 2.325 | 1.55 | 0.775 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 | 0.778 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B27 Photovoltaic power production, residential grid-connected (EPV02)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utilization factor for season-time of day [CF(Z)(Y), I-D] | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Utilization factor for season-time of day [CF(Z)(Y), I-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Utilization factor for season-time of day [CF(Z)(Y), S-D] | | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 |
| Utilization factor for season-time of day [CF(Z)(Y), S-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Utilization factor for season-time of day [CF(Z)(Y), W-D] | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Utilization factor for season-time of day [CF(Z)(Y), W-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fixed O&M (FIXOM) | | 240 | 150 | 86.3 | 60 | 48.8 | 25 | 18.5 | 12 | 12 | 12 | 12 | 12 |
| Maximum capacity growth (GROWTH) | | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 12,000.00 | 7,500.00 | 5,750.00 | 4,000.00 | 3,250.00 | 2,500.00 | 1,850.00 | 1,200.00 | 1,200.00 | 1,200.00 | 1,200.00 | 1,200.00 |
| Fraction of capacity available at peak [PEAK(CON)] | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Residual capacity (RESID) | | 0.0288 | 0.0216 | 0.0144 | 0.0072 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**B28 Wind power production, small scale, local grid (EW01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum capacity allowed [BOUND(BD)] | | | 1 | 1.8 | 2.6 | 3.8 | 5 | 7 | 9 | 11.5 | 14 | 17 | 20 |
| Fixed O&M (FIXOM) | | 18 | 15.3 | 15.3 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 | 14.4 |
| Maximum capacity growth (GROWTH) | | 1.3 | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 1,200.00 | 1,050.00 | 825 | 600 | 575 | 550 | 525 | 500 | 500 | 500 | 500 | 500 |
| Fraction of capacity available at peak [PEAK(CON)] | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Residual capacity (RESID) | | 0.0377 | 0.0377 | 0.0377 | 0.0377 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

## BASE SCENARIOS
## "PROCESS" TECHNOLOGIES
## (PRODUCING ENERGY CARRIERS OTHER THAN ELECTRICITY)

| | | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B29 Biomass, anaerobic digester, village-scale (PBG)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum production [BOUND(BD)O] | | 31.6 | 33 | 37.5 | 45 | 60 | 75 | 97.5 | 120 | 150 | 180 | 207 | 234 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 | 5.51 |
| Residual capacity (RESID) | | 31.6008 | 15.8004 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 | 0.48 |
| Plant operating lifetime [LIFE] | 10 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B30 Biomass, producer gas for cooking, village scale production (PBV01)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum production [BOUND(BD)O] | | 0.5 | 1 | 3 | 6 | 9.4 | 12.8 | 16.2 | 19.6 | 23 | 26.4 | 29.8 | 33.2 |
| Input energy [INP(ENT)c] | | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 | 1.6 |
| Investment cost (INVCOST) | | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 | 26.7 |
| Residual capacity (RESID) | | 0.34 | 0.17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 |
| Plant operating lifetime [LIFE] | 10 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B31 Coal, gasification, current technology for town gas, with by-product coke production (PCG01)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Maximum production [BOUND(BD)O] | | 126 | | | | | | | | | | | |
| Input energy [INP(ENT)c] | | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Investment cost (INVCOST) | | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 | 8.03 |
| Energy carrier output [OUT(ENC)p], gas | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Energy carrier output [OUT(ENC)p], coke | | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Residual capacity (RESID) | | 175 | 175 | 175 | 175 | 116.6667 | 58.3333 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 | 0.71 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B32 Coal, conversion to coke (PCK)** | | | | | | | | | | | | | |
| Minimum production [BOUND(BD)O, LO] | | 3,700.00 | | | | | | | | | | | |
| Maximum production [BOUND(BD)O, HI] | | 4,200.00 | | | | | | | | | | | |
| Annual capacity utilization (CF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Input energy [INP(ENT)c] | | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 |
| Investment cost (INVCOST) | | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 | 1.48 |
| Energy carrier output [OUT(ENC)p], gas | | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 | 0.09 |
| Energy carrier output [OUT(ENC)p], coke | | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 | 0.91 |
| Residual capacity (RESID) | | 4,111.00 | 3,425.83 | 2,740.67 | 2,055.50 | 1,370.33 | 685.1667 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B33 Coal, washing (PCW)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)c] | | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 | 1.11 |
| Investment cost (INVCOST) | | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 | 0.18 |
| Residual capacity (RESID) | | 6,083.00 | 5,069.17 | 4,055.33 | 3,041.50 | 2,027.67 | 1,013.83 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 | 0.22 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |
| **B34 Oil refinery (PORL)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Minimum required production [BOUND(BD)O] | | 5,600.00 | | | | | | | | | | | |
| Maximum production [BOUND(BD)O] | | 5,700.00 | | | | | | | | | | | |
| SO2 emissions | | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 | 0.198 |
| Input energy [INP(ENT)p] | | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Investment cost (INVCOST) | | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 | 1.17 |
| Maximum energy carrier output [OUT(ENC)p], diesel | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Maximum energy carrier output [OUT(ENC)p], gasoline | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Maximum energy carrier output [OUT(ENC)p], kerosene | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Maximum energy carrier output [OUT(ENC)p], LPG | | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| Maximum energy carrier output [OUT(ENC)p], non-energy products | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Maximum energy carrier output [OUT(ENC)p], heavy fuel oil | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Residual capacity (RESID) | | 8,374.00 | 6,978.33 | 5,582.67 | 4,187.00 | 2,791.33 | 1,395.67 | 0 | 0 | 0 | 0 | 0 | 0 |
| Variable O&M (VAROM) | | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

## ADVANCED SCENARIOS
## ELECTRICITY TECHNOLOGIES
## (GENERATING ELECTRICITY OR ELECTRICITY AND CO-PRODUCTS)

| | | | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A1** | **Biomass, steam-cycle, fluidized-bed combustion (EBC01)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Input energy [INP(ENT)c] | | | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 | 6.06 |
| | Investment cost (INVCOST) | | | 427 | 427 | 427 | 427 | 427 | 427 | 427 | 427 | 427 | 427 | 427 |
| | Variable O&M (VAROM) | | | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 | 8.71 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A2** | **Biomass, co-production of F-T liquids and electricity (EBL01)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 | 33.2 |
| | Input energy [INP(ENT)c] | | | | | 5.07 | 5.07 | 5.07 | 5.07 | 5.07 | 5.07 | 5.07 | 5.07 | 5.07 |
| | Investment cost (INVCOST) | | | | | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 | 1,659.00 |
| | Energy carrier output [OUT(ENC)c] | | | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| | Variable O&M (VAROM) | | | | | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 | 1.32 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2010 | | | | | | | | | | | | |
| **A3** | **Biomass, co-production of DME and electricity (EBL02)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | | 44.8 | 44.8 | 44.8 | 44.8 | 44.8 | 44.8 | 44.8 | 44.8 | 44.8 |
| | Maximum capacity growth (GROWTH) | | | | | 1.3 | 1.3 | 1.2 | 1.15 | 1.15 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Input energy [INP(ENT)c] | | | | | 6.12 | 6.12 | 6.12 | 6.12 | 6.12 | 6.12 | 6.12 | 6.12 | 6.12 |
| | Investment cost (INVCOST) | | | | | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 | 2,141.00 |
| | Energy carrier output [OUT(ENC)c] | | | | | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 | 2.1 |
| | Variable O&M (VAROM) | | | | | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2010 | | | | | | | | | | | | |
| **A4** | **Biomass, gasifier-microturbine, co-production of heat and electricity, village scale (EBV02)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 | 71.3 |
| | Input energy [INP(ENT)c] | | | | 5.1 | 5.1 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 | 4.76 |
| | Investment cost (INVCOST) | | | | 2,827.00 | 2,677.00 | 2,427.00 | 2,013.00 | 2,013.00 | 2,013.00 | 2,013.00 | 2,013.00 | 2,013.00 | 2,013.00 |
| | Ratio of electricity-to-heat out (REH) | | | | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 | 1.22 |
| | Variable O&M (VAROM) | | | | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 | 6.55 |
| | Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| | First year technology is available [START] | 2005 | | | | | | | | | | | | |
| **A5** | **Biomass, gasifier-SOFC/microturbine electricity production, village scale (EBV03)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | | | 41.2 | 37.8 | 34.4 | 34.4 | 34.4 | 34.4 | 34.4 | 34.4 |
| | Input energy [INP(ENT)c] | | | | | | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 |
| | Investment cost (INVCOST) | | | | | | 1,649.00 | 1,511.00 | 1,374.00 | 1,374.00 | 1,374.00 | 1,374.00 | 1,374.00 | 1,374.00 |
| | Variable O&M (VAROM) | | | | | | 1.74 | 1.6 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 |
| | Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| | First year technology is available [START] | 2015 | | | | | | | | | | | | |
| **A6** | **Coal, IGCC electricity (EC0C)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 |
| | Fixed O&M (FIXOM) | | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 | 22.3 |
| | Maximum capacity growth (GROWTH) | | | 1.3 | 1.3 | 1.3 | 1.2 | 1.2 | 1.15 | 1.15 | 1.1 | 1.1 | 1.1 | 1.1 |
| | Input energy [INP(ENT)c] | | | 2.38 | 2.27 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 | 2.12 |
| | Investment cost (INVCOST) | | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 | 1,114.00 |
| | Variable O&M (VAROM) | | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 | 0.88 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A7** | **Coal, IGCC electricity, with CO2 capture and sequestration (EC0CS)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | SO2 Emissions | | | | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 |
| | Fixed O&M (FIXOM) | | | | 38.4 | 40.1 | 40.1 | 39.5 | 39.5 | 39.5 | 39.5 | 39.5 | 39.5 | 39.5 |
| | Input energy [INP(ENT)c] | | | | 2.69 | 2.69 | 2.69 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 |
| | Investment cost (INVCOST) | | | | 2,006.00 | 2,006.00 | 2,006.00 | 1,977.00 | 1,977.00 | 1,977.00 | 1,977.00 | 1,977.00 | 1,977.00 | 1,977.00 |
| | Carbon sequestered [OUT(MAT)c] | | | | 213.9 | 213.9 | 213.9 | 186.5 | 186.5 | 186.5 | 186.5 | 186.5 | 186.5 | 186.5 |
| | Variable O&M (VAROM) | | | | 1.59 | 1.59 | 1.59 | 1.57 | 1.57 | 1.57 | 1.57 | 1.57 | 1.57 | 1.57 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2005 | | | | | | | | | | | | |
| **A8** | **Coal, SOFC electricity, with CO2 capture and sequestration (EC0DS)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | | 30.5 | 30.5 | 30.5 | 30.5 | 30.5 | 30.5 | 30.5 | 30.5 | 30.5 |
| | Input energy [INP(ENT)c] | | | | | 2.23 | 2.23 | 2.23 | 2.23 | 2.23 | 2.23 | 2.23 | 2.23 | 2.23 |
| | Investment cost (INVCOST) | | | | | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 | 1,524.00 |
| | Carbon sequestered [OUT(MAT)c] | | | | | 186.1 | 186.1 | 186.1 | 186.1 | 186.1 | 186.1 | 186.1 | 186.1 | 186.1 |
| | Variable O&M (VAROM) | | | | | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 | 1.21 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| | First year technology is available [START] | 2025 | | | | | | | | | | | | |
| **A9** | **Coal, integrated gasifier HSMR combined cycle electricity (EC0E)** | | | | | | | | | | | | | |
| | Availability Factor (AF) | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| | Fixed O&M (FIXOM) | | | | | 23.1 | 23.1 | 23.1 | 23.1 | 23.1 | 23.1 | 23.1 | 23.1 | 23.1 |
| | Input energy [INP(ENT)c] | | | | | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 | 2.34 |

**A10 Coal, integrated gasifier HSMR combined cycle electricity, with CO2 capture and sequestration (EC0ES)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Fixed O&M (FIXOM) | | | | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 | 29.8 |
| Input energy [INP(ENT)c] | | | | 2.52 | 2.52 | 2.52 | 2.52 | 2.52 | 2.52 | 2.52 | 2.52 | 2.52 |
| Investment cost (INVCOST) | | | | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 | 1,489.00 |
| Carbon sequestered [OUT(MAT)c] | | | | 223 | 223 | 223 | 223 | 223 | 223 | 223 | 223 | 223 |
| Variable O&M (VAROM) | | | | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 | 1.18 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A11 Coal, IGCC cogeneration of electricity and high-temperature process heat (ECG03)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 | 0.0258 |
| Fixed O&M (FIXOM) | | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 | 26.9 |
| Input energy [INP(ENT)c] | | | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 | 2.62 |
| Investment cost (INVCOST) | | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 | 1,343.00 |
| Energy carrier output [OUT(ENC)c], process heat | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable O&M (VAROM) | | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 | 1.06 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | |

**A12 Coal, co-production of DME and IGCC-electricity (ECP01)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Fixed O&M (FIXOM) | | | | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 | 29.1 |
| Input energy [INP(ENT)c] | | | | 2.91 | 2.91 | 2.91 | 2.91 | 2.91 | 2.91 | 2.91 | 2.91 | 2.91 |
| Investment cost (INVCOST) | | | | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 | 1,454.00 |
| Energy carrier output [OUT(ENC)c], DME | | | | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 |
| Variable O&M (VAROM) | | | | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A13 Coal, co-production of DME and IGCC-electricity, with CO2 capture and sequestration (ECP01S)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 | 0.0165 |
| Fixed O&M (FIXOM) | | | | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 | 44.7 |
| Input energy [INP(ENT)c] | | | | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 | 3.12 |
| Investment cost (INVCOST) | | | | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 | 2,234.00 |
| Energy carrier output [OUT(ENC)c], DME | | | | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| Carbon sequestered [OUT(MAT)c] | | | | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 | 73.2 |
| Variable O&M (VAROM) | | | | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 | 1.77 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A14 Coal, integrated gasifier-HSMR, co-production of electricity and hydrogen (ECP02)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Fixed O&M (FIXOM) | | | | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 | 91.3 |
| Input energy [INP(ENT)c] | | | | 13.54 | 13.54 | 13.54 | 13.54 | 13.54 | 13.54 | 13.54 | 13.54 | 13.54 |
| Investment cost (INVCOST) | | | | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 | 4,563.00 |
| Energy carrier output [OUT(ENC)c], H2 | | | | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 | 6.2 |
| Variable O&M (VAROM) | | | | 3.62 | 3.62 | 3.62 | 3.62 | 3.62 | 3.62 | 3.62 | 3.62 | 3.62 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A15 Coal, integrated gasifier-HSMR, co-production of electricity and hydrogen, with CO2 capture and sequestration (ECP02S)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Fixed O&M (FIXOM) | | | | 202.4 | 202.4 | 202.4 | 202.4 | 202.4 | 202.4 | 202.4 | 202.4 | 202.4 |
| Input energy [INP(ENT)c] | | | | 23.21 | 23.21 | 23.21 | 23.21 | 23.21 | 23.21 | 23.21 | 23.21 | 23.21 |
| Investment cost (INVCOST) | | | | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 | 10,122.00 |
| Energy carrier output [OUT(ENC)c], H2 | | | | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 | 10.7 |
| Carbon sequestered [OUT(MAT)c] | | | | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 | 2,053.00 |
| Variable O&M (VAROM) | | | | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 | 8.02 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A16 Coal, co-production of electricity, methanol, and high-temperature process heat (ECP03)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 |
| Fixed O&M (FIXOM) | | | | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 | 35 |
| Input energy [INP(ENT)c] | | | | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 | 4.36 |
| Investment cost (INVCOST) | | | | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 | 1,750.00 |
| Energy carrier output [OUT(ENC)c], MeOH | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy carrier output [OUT(ENC)c], process heat | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable O&M (VAROM) | | | | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | |

**A17 Coal, co-production of electricity, methanol, high-temperature process heat, and towngas (ECP04)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| SO2 Emissions | | | | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 | 0.0208 |
| Fixed O&M (FIXOM) | | | | 39.2 | 39.2 | 39.2 | 39.2 | 39.2 | 39.2 | 39.2 | 39.2 | 39.2 |
| Input energy [INP(ENT)c] | | | | 5.64 | 5.64 | 5.64 | 5.64 | 5.64 | 5.64 | 5.64 | 5.64 | 5.64 |
| Investment cost (INVCOST) | | | | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 | 1,958.00 |
| Energy carrier output [OUT(ENC)c], town gas | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy carrier output [OUT(ENC)c], MeOH | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Energy carrier output [OUT(ENC)c], process heat | | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Variable O&M (VAROM) | | | | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 | 1.55 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | |

**A18 Hydrogen fuel cell, distributed combined heat and power (EHG01)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| H2 trans./distr. cost [DELIV(ENT)] | | | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 | 2.78 |
| Fixed O&M (FIXOM) | | | | 20 | 18 | 16 | 14 | 10 | 10 | 10 | 10 | 10 |
| Maximum capacity growth (GROWTH) | | | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Input energy [INP(ENT)c] | | | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 | 2.44 |
| Investment cost (INVCOST) | | | | 500 | 400 | 300 | 300 | 250 | 250 | 250 | 250 | 250 |
| Ratio of electricity-to-heat out (REH) | | | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 | 1.73 |
| Variable O&M (VAROM) | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A19 Natural gas, advanced gas turbine combined cycle electricity production, with $CO_2$ capture and sequestration (ENG02S)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Fixed O&M (FIXOM) | | | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 | 18.1 |
| Input energy [INP(ENT)c] | | | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 | 1.97 |
| Investment cost (INVCOST) | | | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 | 1,008.00 |
| Carbon sequestered [OUT(MAT)c] | | | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 | 105.9 |
| Variable O&M (VAROM) | | | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | |

**A20 Natural gas, gas turbine combined cycle co-production of electricity and F-T liquids (ENG05)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Fixed O&M (FIXOM) | | | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 | 50.1 |
| Input energy [INP(ENT)c] | | | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 | 13.6 |
| Investment cost (INVCOST) | | | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 | 4,937.00 |
| Energy carrier output [OUT(ENC)c], F-T liquids | | | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 | 6.67 |
| Variable O&M (VAROM) | | | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 | 3.19 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | |

**A21 Natural gas, distributed fuel cell, combined heat and power production (ENG06)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Fixed O&M (FIXOM) | | | | 20 | 18 | 16 | 14 | 12 | 12 | 12 | 12 | 12 | 12 |
| Input energy [INP(ENT)c] | | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 | 3.23 |
| Investment cost (INVCOST) | | | | 500 | 400 | 350 | 350 | 300 | 300 | 300 | 300 | 300 | 300 |
| Ratio of electricity-to-heat out (REH) | | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 | 1.307 |
| Variable O&M (VAROM) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | | |

**A22 Photovoltaic power production, centralized plant (EPV01)**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Utilization factor for season-time of day [CF(Z)(Y), I-D] | | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 | 0.5 |
| Utilization factor for season-time of day [CF(Z)(Y), I-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Utilization factor for season-time of day [CF(Z)(Y), S-D] | | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 |
| Utilization factor for season-time of day [CF(Z)(Y), S-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Utilization factor for season-time of day [CF(Z)(Y), W-D] | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Utilization factor for season-time of day [CF(Z)(Y), W-N] | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Fixed O&M (FIXOM) | | 140 | 120 | 60 | 37.5 | 27 | 15 | 12 | 10 | 10 | 10 | 10 | 10 |
| Maximum capacity growth (GROWTH) | | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| Input energy [INP(ENT)c] | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | 7,000.00 | 6,000.00 | 4,000.00 | 2,500.00 | 1,800.00 | 1,500.00 | 1,200.00 | 1,000.00 | 1,000.00 | 1,000.00 | 1,000.00 | 1,000.00 |
| Fraction of capacity available at peak [PEAK(CON)] | | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| Variable O&M (VAROM) | | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 | 0.019 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 1995 | | | | | | | | | | | | |

**A23 Wind power production, large-scale remote farm with HVDC transmission to demand centers (EW02)**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Maximum capacity allowed [BOUND(BD)] | | | 1 | 5 | 10 | 20 | 32 | 52 | 84 | 132 | 186 | 237 | 300 |
| Fixed O&M (FIXOM) | | | 7 | 6 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Maximum capacity growth (GROWTH) | | | 1.3 | 1.3 | 1.2 | 1.2 | 1.2 | 1.2 | 1.15 | 1.15 | 1.15 | 1.15 | 1.15 |
| Input energy [INP(ENT)c] | | | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Investment cost (INVCOST) | | | 1,050.00 | 860 | 670 | 646 | 625 | 604 | 580 | 580 | 580 | 580 | 580 |
| Fraction of capacity available at peak [PEAK(CON)] | | | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 | 0.45 |
| Variable O&M (VAROM) | | | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 | 0.556 |
| Plant operating lifetime [LIFE] | 20 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

## ADVANCED SCENARIOS
## "PROCESS" TECHNOLOGIES
## (PRODUCING ENERGY CARRIERS OTHER THAN ELECTRICITY)

| | | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A24 Biomass, ethanol production by enzymatic hydrolysis (PBEO1)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 | 4.17 |
| Investment cost (INVCOST) | | | 129.3 | 129.3 | 76.8 | 33.2 | 22.4 | 18.6 | 13.4 | 13.4 | 13.4 | 13.4 | 13.4 |
| Variable O&M (VAROM) | | | 5.17 | 5.17 | 3.07 | 1.33 | 0.9 | 0.74 | 0.53 | 0.53 | 0.53 | 0.53 | 0.53 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A25 Coal, town gas production (advanced gasifier) (PCG02)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 | 1.27 |
| Investment cost (INVCOST) | | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| Variable O&M (VAROM) | | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 | 0.72 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A26 Coal, hydrogen production with conventional technology (PCH01)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| Investment cost (INVCOST) | | | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 | 35.3 |
| Variable O&M (VAROM) | | | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 | 1.41 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | | |
| **A27 Coal, H2 production from coal+CBM, with CO2 injected for enhanced CBM production (PCH02)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | | | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 | 0.82 |
| Investment cost (INVCOST) | | | | | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 | 13.9 |
| Variable O&M (VAROM) | | | | | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 | 1.68 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | | |
| **A28 Coal, methanol production (PCL02)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 | 1.81 |
| Investment cost (INVCOST) | | | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 | 47.28 |
| Variable O&M (VAROM) | | | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 | 1.89 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A29 Coal, F-T liquids production (PCL03)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 |
| Investment cost (INVCOST) | | | | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 | 34 |
| Variable O&M (VAROM) | | | | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 | 1.35 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2005 | | | | | | | | | | | | |
| **A30 Coal, F-T liquids production, with CO2 capture and sequestration (PCL03S)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 | 1.78 |
| Investment cost (INVCOST) | | | | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 | 41 |
| Carbon sequestered [OUT(MAT)p] | | | | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 | 97.96 |
| Variable O&M (VAROM) | | | | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 | 2.28 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | | |
| **A31 Coal, DME production (PCL04)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 | 0.85 |
| Input energy [INP(ENT)p] | | | | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 | 1.56 |
| Investment cost (INVCOST) | | | | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 | 20.9 |
| Variable O&M (VAROM) | | | | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 | 0.84 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2010 | | | | | | | | | | | | |
| **A32 Natural gas, methanol production (PNG01)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Input energy [INP(ENT)p] | | | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 | 1.54 |
| Investment cost (INVCOST) | | | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 | 20.2 |
| Variable O&M (VAROM) | | | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 | 0.81 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |
| **A33 Natural gas, F-T liquids production (PNG02)** | | | | | | | | | | | | | |
| Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| Input energy [INP(ENT)p] | | | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 |
| Investment cost (INVCOST) | | | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 | 20.7 |
| Variable O&M (VAROM) | | | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 | 0.83 |
| Plant operating lifetime [LIFE] | 30 | | | | | | | | | | | | |
| First year technology is available [START] | 2000 | | | | | | | | | | | | |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **A34** | **Natural gas, F-T liquids production, with CO2 capture and sequestration (PNG02S)** | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| | Input energy [INP(ENT)p] | | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 | 1.67 |
| | Investment cost (INVCOST) | | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 | 21.6 |
| | Carbon sequestered [OUT(MAT)p] | | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 | 12.07 |
| | Variable O&M (VAROM) | | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 | 0.886 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | |
| | First year technology is available [START] | 2005 | | | | | | | | | | |
| **A35** | **Natural gas, hydrogen production (PNG03)** | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| | Input energy [INP(ENT)p] | | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| | Investment cost (INVCOST) | | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| | Variable O&M (VAROM) | | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | |
| | First year technology is available [START] | 2005 | | | | | | | | | | |
| **A36** | **Natural gas, hydrogen production, with CO2 capture and sequestration (PNG03S)** | | | | | | | | | | | |
| | Availability Factor (AF) | | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| | Input energy [INP(ENT)p] | | | 1.2 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 | 1.3 |
| | Investment cost (INVCOST) | | | 15 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 | 13.8 |
| | Carbon sequestered [OUT(MAT)p] | | | 39.05 | 39.05 | 39.05 | 39.05 | 39.05 | 39.05 | 39.05 | 39.05 | 39.05 |
| | Variable O&M (VAROM) | | | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | |
| | First year technology is available [START] | 2010 | | | | | | | | | | |
| **A37** | **Natural gas, DME production (PNG04)** | | | | | | | | | | | |
| | Availability Factor (AF) | | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| | Input energy [INP(ENT)p] | | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 | 1.45 |
| | Investment cost (INVCOST) | | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 | 19.4 |
| | Variable O&M (VAROM) | | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 | 0.78 |
| | Plant operating lifetime [LIFE] | 30 | | | | | | | | | | |
| | First year technology is available [START] | 2005 | | | | | | | | | | |

## NOTES ON BASE SCENARIO TECHNOLOGIES

In the following notes, the numbering of the technologies corresponds to that in the preceding table.

### B1. EBV01: Biomass village CHP-ICE

Technology characteristics are for a 200 kW corn-stalk gasification combined heat and power plant, and the cost and performance data were taken from a project being constructed in Jilin province. Liu, Wang and DeLaquil (2001) provide a description of the project, and Li, *et al.* (2001) provide cost details. Emissions data were taken from a Fairbanks-Morse engine datasheet for a same-size engine operating on natural gas. Capital cost reductions of 15% per five-year period (2.8% annual) were assumed between 2000 and 2010. A further 10% cost reduction was assumed from 2010 to 2015 period and the capital cost remained constant at that level from 2015 onward.

### B2. EC01: Coal-fired, <=100MW

See Chen and Wu (2001) and Wu and Chen (2001).

### B3. EC02: Coal-fired, 100-200MW

See Chen and Wu (2001) and Wu and Chen (2001).

### B4. EC03: Coal-fired, 200-300MW, ESP

See Chen and Wu (2001) and Wu and Chen (2001).

### B5. EC04: Coal-fired, >=300MW, ESP

See Chen and Wu (2001) and Wu and Chen (2001).

### B6. EC05: Coal-fired, >=300MW, ESP, Dry FGD

See Chen and Wu (2001) and Wu and Chen (2001).

### B7. EC06: Coal-fired, >=300MW, ESP, Wet FGD

See Chen and Wu (2001) and Wu and Chen (2001).

### B8. EC07: Coal-fired, >=300MW, ESP, $SO_x/NO_x$

See Chen and Wu (2001) and Wu and Chen (2001).

### B9. EC08: Coal pulverized, 500 MW, with FGD

Technology characteristics are based on those for a 500 MW pulverized coal steam-electric plant with flue gas desulphurization, as indicated in Table 8.4 of Williams (2000). Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are those for a new coal steam-electric plant in the USA with best available control technology (Table 8.1 in Williams, 2000). Plant lifetime is based on EPRI (1989).

### B10. EC09: Atmospheric-Pressure Fludized Bed

See Chen and Wu (2001) and Wu and Chen (2001).

### B11. EC0A: Pressurized Fluidized Bed Combustion

See Chen and Wu (2001) and Wu and Chen (2001).

## B12. EC0B: Coal ultrasupercritical steam plant

Technology characteristics are based on those for a 400 MW ultrasupercritical pulverized coal steam-electric plant, as indicated in Table 8.9 of Williams (2000). Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are those for a new coal steam-electric plant in the USA with best available control technology (Table 8.1 in Williams, 2000). Plant lifetime is based on EPRI (1989).

## B13. ECG01: Coal LTH & Power

See Chen and Wu (2001) and Wu and Chen (2001).

## B14. ECG02: PCC steam el + process heat

Technology characteristics are based on those for a pulverized coal steam-electric plant producing 400 MW of electricity and 400 MW of steam, as indicated in Table 8.8 of Williams (2000). Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions per kWh of electricity generated are assumed to be the same as for a new coal steam-electric plant in the USA with best available control technology. New coal-steam plant BACT emissions are given by Williams (2000) in Table 8.1. Plant lifetime is assumed to be the same as a pulverized coal-steam electric-only plant.

## B15. ECG04: Lower-emissions steam-cycle electricity and low-temp. district heating

This technology was derived from B13 to represents modern technology with best-available emissions control equipment for $SO_2$. $SO_2$ emissions are those for a new coal steam-electric plant in the USA with best available control technology (Table 8.1 in Williams, 2000). The increase in capital costs was derived from data for technologies B6, B7 and B8.

## B16. ECH01: Heating plant - Coal central boiler

See Chen and Wu (2001) and Wu and Chen (2001).

## B17. ECH02: Coal steam/heat, advanced

Technology characteristics are based on those for a stand-alone 400 MW steam production plant (ultrasupercritical pulverized coal), as indicated in Table 8.8 in Williams (2000). Williams indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are based on emissions given by Williams (2000) in Table 8.1 for a new coal steam-electric plant with best available control technology. The emissions per-kWh given in the table are multiplied by the efficiency of the electricity plant and divided by the efficiency of the heat plant to derive emissions per unit heat output. Plant lifetime is assumed to be the same as for the pulverized coal steam-electric plant.

## B18. EG01: Geothermal power generation

See Chen and Wu (2001) and Wu and Chen (2001).

## B19. EH01: Large hydropower

See Chen and Wu (2001) and Wu and Chen (2001).

## B20. EH02: Small hydropower

See Chen and Wu (2001) and Wu and Chen (2001).

## B21. EN01: Nuclear

See Chen and Wu (2001) and Wu and Chen (2001).

## B22. ENG01: NG turbine peaking plant

See Chen and Wu (2001) and Wu and Chen (2001).

## B23. ENG02: NG CC - air-cooled turbine

Technology characteristics are based on those for a 506 MW natural gas combined cycle using air-cooled gas turbine blades (Frame 7F technology), as indicated in Table 8.4 in Williams (2000). Capital investment is assumed to be $600/kW (Wu and Chen, 2001; Chen and Wu, 2001). Williams' Table 8.4 gives annual fixed O&M costs and annual non-fuel variable O&M costs. $SO_2$ emissions are from Table 8.1 in Williams (2000), but adjusted for the lower efficiency of the 7F-based NGCC relative to the 7H-based NGCC, on which the emissions given in Table 8.1 are based. Plant lifetime is based on EPRI (1989).

## B24. ENG04: NG CC – cogen, advanced

Technology characteristics are based on those for a plant cogenerating 400 MW of steam and 400 MW of electricity using a natural gas combined cycle with steam-cooled gas turbine blades (Frame H gas turbine technology), as indicated in Table 8.5 in Williams (2000). Williams (2000) indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions per kWh of electricity generated are assumed to be 1.31 times those for a NG CC electric-only plant. The electric-only emissions are given by Williams (2000) in Table 8.1. The 1.31 multiplier is based on Table 8.5 in Williams, which indicates that the cogeneration plant consumes 1.31 times as much fuel as a 400 MW IGCC electric-only plant. Plant lifetime is assumed to be the same as for NGCC – air-cooled turbine.

## B25. EO01: Traditional oil-fired plant

See Chen and Wu (2001) and Wu and Chen (2001).

## B26. EO02: Oil-fired combined cycle plant

See Chen and Wu (2001) and Wu and Chen (2001).

## B27. EPV02: Solar photovoltaic electricity, distributed grid-connected

Technology characteristics represent a composite for residential and commercial grid-connected applications ranging from individual household systems to building-integrated systems. Current system costs were taken from Voravate, *et al.* (2000) and Zhao (2001). Projected future cost reductions were derived from Zhao (2001) and Turkenburg (2000). The technology was modeled with a fixed capacity utilization factor [CF] for summer, intermediate-season, and winter days as shown in the parameter table. The 30% peak coincidence factor was estimated to be representative of China as a whole.

## B28. EW01: Wind power plant – local

Technology characteristics are for a 10 to 20 MW grid-connected wind farm, which is constructed without need for any new transmission lines. Current system capital and O&M costs were taken from Lew, *et al.* (1998), and projections for future costs are taken from Brown (2001) and Turkenburg (2000). Significant Chinese manufacturing content was assumed to be achieved by 2010, and by 2030 the long-term potential cost was achieved. The 30% peak coincidence factor was estimated to be representative of good wind-sites in China.

## B29. PBG: Village-scale biogas production for cooking

See Chen and Wu (2001) and Wu and Chen (2001).

## B30. PBV01: Village-scale producer gas production for cooking

Based on Gu, *et al.* (2001) for producer gas supply from crop residues, with gas used for cooking for a 200 household village. Cooking gas use is 5 $m^3$/day/household and gas heating value is 5 MJ/$m^3$. 1 kg crop residue produces 2 $m^3$ gas. Assume residue heating value of 16 MJ/kg. Total investment is 400,000 yuan. Total O&M, including fuel collection is 30,000 yuan. Fuel collection cost is 4000 yuan/year.

## B31. PCG01: Coal - towngas

See Chen and Wu (2001) and Wu and Chen (2001).

## B32. PCK: Coke making

See Chen and Wu (2001) and Wu and Chen (2001).

## B33. PCW: Coal washing

See Chen and Wu (2001) and Wu and Chen (2001).

## B34. PORL: Oil refinery

See Chen and Wu (2001) and Wu and Chen (2001).

# NOTES ON ADVANCED SCENARIO TECHNOLOGIES

## A1. EBC01: Biomass, steam-cycle, fluidized-bed combustion

Based on personal communication with Tsinghua University Professor Zhang Xiliang. The investment is 3.5 million yuan for 1 MW output. Feedstock of rice hulls plus wood chips is consumed at rate of 30 tonnes/day. (1.5 to 1.8 kg/kWh) 18 hours/day operation; 6 million kWh/yr. O&M cost is 1.69 million yuan/yr.

## A2. EBL01: Biomass FT + el

Technology characteristics are based on those for a plant designed by Bechtel (Choi *et al.*, 1997; Bechtel, 1998b) consuming 3220 metric tonnes per day of wood containing 37.9% water (37.5 TJ/day of input wood). The biomass is dried to 24% moisture before gasification in an indirectly-heated gasifier (Battelle Columbus Laboratory design). The resulting syngas is passed once through a liquid-phase Fischer-Tropsch synthesis reactor, producing 382 bbl/day (2005 GJ/day) of F-T gasoline and 775 bbl/day (4482 GJ/day) of F-T distillate fuel. Unconverted syngas is burned in a gas turbine combined cycle. The net electricity export from the plant is 85.8 MW. Annual O&M costs are assumed to be 4% of initial capital cost, as for most of the coal-based systems discussed above. $SO_x$ emissions are assumed to be zero since most biomass contains little or no sulfur. Plant lifetime is assumed to be the same as for coal-based conversion technologies. [Note: the capital cost per kW of F-T liquid produced with this system is $\$1891/kW_{F\text{-}T}$. For comparison, Larson and Jin (1999) give an independently-derived capital cost estimate of $\$1894/kW_{F\text{-}T}$ for a system with similar design (including the same gasifier design), but with much smaller production capacity (1500 GJ/day F-T liquids; 9.4 MW electric). This comparison suggests that the Bechtel capital cost estimate is high and/or the Larson/Jin estimate is low.]

## A3. EBL02: Biomass DME + el

The characteristics of this technology are based on Consonni and Larson (1996) for wood-to-syngas energy efficiency, Bechtel (1998b) for cost of syngas production from wood, APCI (1993) for cost of once-through liquid-phase synthesis of DME, and our own assumptions for the cost ($400/kW) and efficiency (50% LHV) of the gas turbine combined cycle that would be integrated into the system to burn unconverted syngas to make 85 MW of electricity. (The relatively low cost of the GTCC compared to a stand-alone GTCC accounts for the fact that it would share some equipment with the syngas production and synthesis plants.) The DME production rate is 176 MW. The wood feed rate is 520 MW (635 tonnes/day at 50% moisture content). Annual O&M costs are assumed to be 4% of initial capital cost. $SO_x$ emissions are assumed to be zero since most biomass contains little or no sulfur. Plant lifetime is assumed to be the same as for coal-based conversion technologies.

## A4. EBV02: Biomass Village CHP-MicroT

Technology characteristics are based on those for a village-scale plant design based on Henderick and Williams (2000). Dry corn stalks are supplied to an air-blown downdraft gasifier generating producer gas that is first cleaned and then passed into a storage system. Gas leaving the storage system is supplied either as cooking fuel to village homes, or it is burned in a microturbine to generate 75 kW of electricity. The waste heat from the microturbine is recovered and circulated through a district heating system to village homes. The system consumes 650 tonnes/year of corn stalks (16.5 GJ/t LHV) and delivers 1100 GJ of cooking gas plus 1500 GJ of district heat while generating 473,000 kWh per year. In the first period when the system is available to Markal, the capital cost is based on a microturbine cost of $750/kW. In the second period, this is assumed to be reduced to $600/kW. The microturbine cost reaches its "$N^{th}$-plant" level of $350/kW in the third period. Microturbine efficiency in the initial two periods is 28% and increases to 30% in the third period and all subsequent periods. These efficiencies are based on discussion in Henderick and Williams. Henderick and Williams also give alternative costs for the district heating network. The total capital cost in the first three periods assumes a DH system cost

equal to the base case presented by Henderick and Williams. In the fourth period and beyond, the DH system cost is based on Henderick and Williams' low-cost case. Half of the maintenance costs indicated by Henderick and Williams are assumed to be fixed O&M costs. The other half plus labor salaries are assumed to constitute variable costs. $SO_x$ emissions are zero (no sulfur in the biomass).

## A5. EBV03: Biomass Village SOFC-MicroT hybrid (el only)

Technology characteristics are based on those for a village-scale plant design based on Kartha *et al.* (2000). Dry biomass is supplied to an air-blown downdraft gasifier generating producer gas that is first cleaned, compressed and preheated (using gas turbine exhaust heat) before passing to a solid-oxide fuel cell that consumes about 85% of the energy in the producer gas and produces 149 kW of electricity. The fuel cell exhaust is burned in a microturbine that generates an additional 50 kW of electricity. The gas turbine exhaust passes to a recuperator that preheats the SOFC feed gas and the microturbine's compressor outlet air. Total net electricity output is 199 kW. The "$N^{th}$-plant" capital cost is given by Kartha *et al.* as $1374/kW. In the first period of introduction, the cost is assumed to be 1.2*1374. In the second period it is assumed to be 1.1*1374. Cost reaches $N^{th}$-plant level in third period. Based on Kartha *et al.*, total annual O&M cost is 5% of initial capital. We assumed half of this is fixed cost and half is variable cost. $SO_x$ emissions are zero (no sulfur in the biomass).

## A6. EC0C: IGCC electricity

Technology characteristics are based on those for a 400 MW IGCC plant using a Destec $O_2$-blown gasifier coupled with a gas turbine combined cycle with steam-cooled gas turbine blades, as indicated in Table 8.10 (also notes of Table 8.7) in Williams (2000). Williams indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$, $NO_x$, and PM emissions are from Table 8.1 in Williams (2000). Plant lifetime and construction time are from EPRI (1989).

## A7. EC0Cs: IGCC electricity with $CO_2$ capture/sequestration

Technology characteristics are based on those for a 400 MW IGCC plant with cold $CO_2$ recovery from synthesis gas (for 2005 thru 2015) and with warm $CO_2$ recovery (for 2020 and beyond), as indicated in Table 8.10 of Williams (2000). $CO_2$ capture rate is 0.210 kgC/kWh * (44/12) = 0.770 $kgCO_2$/kWh for cold recovery (Table 8.10), or 213.9 $ktCO_2/PJ_e$. For warm recovery, the capture rate is 0.671 $kgCO_2/kWh_e$ [from Table 8.9: capture rate = (184*(45.9/41.5)-20.4)*44/12], or 186.5 $ktCO_2/PJ_e$. $CO_2$ sequestration and transportation costs are included as part of the capital cost, as explained in the general notes above. (These are $225/kW for cold $CO_2$ and $196/kW for warm $CO_2$ recovery.) Williams indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are assumed to be the same as for an IGCC without $CO_2$ capture. These numbers are from Table 8.1 in Williams (2000). Plant lifetime is based on EPRI (1989).

## A8. EC0DS: Coal SOFC with $CO_2$ capture/sequestration

Technology characteristics are based on those for a 400 MW with gasifier and solid oxide fuel cell, with $CO_2$ concentrated in the SOFC and then compressed to 135 bar for transport and sequestration (Simbeck, 1999, Table 2). $CO_2$ sequestration and transportation costs are included as part of the capital cost, as explained in the general notes above. The $CO_2$ capture rate is 0.67 metric tonnes $CO_2$ per MWh electricity (from detailed flow sheets provided in personal communication by Simbeck to Tom Kreutz at Princeton.) Simbeck indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are assumed to be zero. We assume plant life is as indicated for IGCC electricity systems.

## A9. EC0E: Coal HSMR electricity

This is a gasification-based system with hydrogen separation using an advanced membrane reactor, plus a gas turbine combined cycle ("Frame H" gas turbine) burning $H_2$ (Kreutz, 2001). Net power output is

494MW. $CO_2$ is vented. Total O&M is assumed to be 4% of capital investment per year, split equally between fixed and variable O&M. Plant lifetime is as assumed for other coal technologies. There are zero sulfur emissions from the facility.

## A10. EC0ES: Coal - HSMR electricity, with $CO_2$ capture/sequestration

This is a gasification-based system with hydrogen separation using an advanced membrane reactor, plus gas turbine combined cycle ("Frame H" gas turbine) burning $H_2$ (Kreutz, 2001). Net power output is 458MW. $CO_2$ is captured at a rate of 368.1 tonnes/hr (or 0.804 t/MWh, 223 kt/$PJ_e$) and compressed to 100 bar. As for most of the other coal systems, total O&M is assumed to be 4% of capital investment per year, split equally between fixed and variable O&M. Plant lifetime is as assumed for other coal technologies. There are zero sulfur emissions from the facility. Equivalent capital costs are included in the investment cost to account for transport and sequestration capacity to handle 368 $tCO_2$ per hour, with cost calculated as discussed in above general notes.

## A11. ECG03: IGCC electricity + process heat

Technology characteristics are based on those for a plant producing 400 MW of electricity and 400 MW of steam, as indicated in Table 8.7 of Williams (2000). The plant uses a Destec coal gasifier and combined cycle with steam-cooled gas turbine blades. Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions per kWh of electricity generated are assumed to be the same as those for an IGCC electric-only plant. The IGCC electric-only emissions are given by Williams (2000) in Table 8.1. Plant lifetime and construction time are assumed to be the same as for IGCC electric-only.

## A12. ECP01: IGCC el + DME

Technology characteristics are based on those for "Case 7" in APCI (1993), where pure DME and electricity are co-produced using 35% of the syngas from a Shell gasifier. This syngas undergoes "once-through" processing in a liquid-phase synthesis reactor, with unconverted gas directed to the combined cycle for electricity generation. APCI gives detailed mass and energy balances for the 35% of syngas that passes through the synthesis reactor. The 65% of syngas that bypasses the synthesis reactor goes directly to a frame H gas turbine combined cycle, where it is assumed to be converted to electricity with a lower hearing value energy efficiency of 60%. Total net electricity output from the full facility is 492 MW, with a net output of 478.1 MW after the parasitic load is satisfied. DME production is 176 MW (LHV). Coal consumption is 1333 MW, which is back-calculated from figures given by APCI assuming a Shell coal gasifier cold-gas efficiency of 80% (Synthetic Fuels Associates, 1983). The total plant capital cost is estimated as follows. The DME synthesis portion of the plant (processing 35% of the syngas) costs $67.5 million (APCI, 1993). A pure IGCC consuming 1333 MW of coal would produce 600 MW of electricity and cost about $1100/kW (Williams, 2000). The syngas production section of such a plant would be identical to the one needed for the combined DME/electricity plant, but the gas turbine combined cycle would be smaller (492 MW). Assuming a credit of $300/kW for 108 MW (600-492) gives a capital cost for syngas production plus GTCC sections of the plant of 600,000*1100 – 108,000*300 = $628 million. Together with the synthesis section of the plant, the total capital required is $695 million. Emissions of $SO_x$ are assumed to be reduced from an IGCC-only plant by 21% [= 1 – (600*.65)/492]. (This assumes that the unconverted syngas from the DME synthesis reactor is completely free of sulfur.)

## A13. ECP01S: IGCC el + DME, with $CO_2$ capture/sequestration

Technology characteristics are based on those for "Case 7" in APCI (1993), where pure DME and electricity are co-produced using 35% of the syngas from a Shell gasifier. This syngas undergoes "once-through" processing in a liquid-phase synthesis reactor, with unconverted gas directed to the combined cycle for electricity generation. APCI gives mass/energy balances and capital cost estimate for the system that processes the 35% of syngas through the synthesis reactor. The 65% of syngas that bypasses the synthesis reactor goes directly to a frame H oxygen-syngas gas turbine combined cycle, where it is

assumed to be converted to electricity with a lower hearing value energy efficiency of 60%. Total electricity generation from the full facility is 492 MW, with a net output of 446.1 MW after meeting electricity needs for synthesis area and $CO_2$ compression to 100 bar.[1] DME production is 176 MW (LHV). Coal consumption is 1333 MW, which is back-calculated from figures given by APCI assuming a Shell coal gasifier cold-gas efficiency of 80% (Synthetic Fuels Associates, 1983). The total plant capital cost is estimated as follows. The DME synthesis portion of the plant (processing 35% of the syngas) costs $67.5 million (APCI, 1993). A pure IGCC consuming 1333 MW of coal would produce 600 MW of electricity and cost about $1100/kW (Williams, 2000). The syngas production section of such a plant would be identical to the one needed for the combined DME/electricity plant, but the gas turbine combined cycle would be smaller (492 MW). Assuming a credit of $300/kW for 108 MW (600-492) gives a capital cost for syngas production plus GTCC sections of the plant of 600,000*1100 – 108,000*300 = $628 million. Together with the synthesis section of the plant, the total capital required is $695 million. We increase this estimate by 10% ($765 million total) to account for the larger ASU that would be needed to supply $O_2$ to the gas turbine in addition to the gasifier. Since the DME facility in the APCI report does not include any $CO_2$ capture, we have estimated the costs for this based on mass flow of $CO_2$ that could be captured (217,689 $m^3$ $CO_2$/hour according to APCI mass/energy balance) an estimate for the added cost of carbon capture at a facility where a concentrated stream of $CO_2$ is available from the process. (This is a capture rate of 117,552 $kgCO_2$/hr, or 263 $kgCO_2$/MWh, or 73.2 kt/$PJ_e$.) We use a capital cost of $628 per $m^3CO_2$/hour for capture of $CO_2$ (see general notes above). As in other cases described above, an additional capital cost ($94 million) is included for transportation and sequestration corresponding to $5/$tCO_2$. Annual O&M costs are assumed to be 4% of total initial capital investment. Emissions of $SO_x$ are assumed to be reduced from an IGCC-only plant by 21% [= 1 – (600*.65)/492]. (This assumes that the unconverted syngas from the DME synthesis reactor is completely free of sulfur.)

## A14. ECP02: Coal - HSMR el + $H_2$

This is a gasification-based system with hydrogen separation using an advanced membrane reactor producing 788 $MW_{th}$ of pressurized (60 bar) $H_2$ plus 85.4 MW electricity from an oxygen-raffinate turbine (Kreutz, 2001). $CO_2$ is vented. As for most of the other coal systems, total O&M is assumed to be 4% of capital investment per year, split equally between fixed and variable O&M. Plant lifetime is as assumed for other coal technologies. There are zero sulfur emissions from the facility.

## A15. ECP02S: Coal - HSMR el + $H_2$, with $CO_2$ capture/sequestration

This is a gasification-based system with hydrogen separation membrane reactor (Kreutz, 2001) producing 788 $MW_{th}$ of pressurized (60 bar) $H_2$ plus 49.8 MW electricity from an oxygen-raffinate turbine. $CO_2$ is captured at a rate of 368.1 tonnes/hr (or 7.392 t/MWh, 2053 kt/$PJ_e$) and compressed to 100 bar. As for most of the other coal systems, total O&M is assumed to be 4% of capital investment per year, split equally between fixed and variable O&M. Plant lifetime is as assumed for other coal technologies. There are zero sulfur emissions from the facility. Equivalent capital costs are included in the investment cost to account for transport and sequestration capacity to handle 368 $tCO_2$ per hour, with cost calculated as discussed in above general notes.

## A16. ECP03: IGCC el + heat + methanol

Technology characteristics are based on those for a plant producing 400 MW of electricity, 400 MW of steam, and 400 MW of methanol, as indicated in Table 8.11 of Williams (2000). The plant uses a Destec coal gasifier and combined cycle with steam-cooled gas turbine blades. Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions per kWh of electricity generated are assumed to be the same as those for an IGCC electric-

[1] Blok *et al.* (1997) indicate compression electricity requirements of 285 $kJ_e/kgCO_2$ to compress $CO_2$ from 1.3 bar to 100 bar. Assuming $CO_2$ density is 1.85 kg/$m^3$ and $CO_2$ flow rate of 217,689 $m^3$/hr gives an electricity requirement of 31.9 MW for $CO_2$ compression. Synthesis area requires 13.9 MW of electricity (APCI, 1993).

only plant. The IGCC electric-only emissions are given by Williams (2000) in Table 8.1. Plant lifetime is assumed to be the same as for IGCC electric-only.

## A17. ECP04: IGCC el + heat + methanol + towngas

Technology characteristics are based on those for a plant producing 400 MW of electricity, 400 MW of steam, 400 MW of methanol, and 400 MW of town gas, as indicated in Table 8.12 of Williams (2000). The plant uses a Destec coal gasifier and combined cycle with steam-cooled gas turbine blades. Williams indicates annual non-fuel O&M costs of 4% of capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions per kWh of electricity generated are assumed to be the same as those for an IGCC electric-only plant. The IGCC electric-only emissions are given by Williams (2000) in Table 8.1. Plant lifetime is assumed to be the same as for IGCC electric-only.

## A18. EHG01: Hydrogen fuel cell, distributed combined heat and power

Characteristics estimated for a 100 kW system using a proton exchange membrane fuel cell (Tom Kreutz, Princeton, personal communication, based on Kreutz and Ogden, 2000).

## A19. ENG03S: NG CC - steam-cooled turb. w/$CO_2$ capture

Technology characteristics are based on those for a 400 MW natural gas combined cycle using steam-cooled gas turbine blades (Frame H gas turbine technology) and flue gas scrubbing of $CO_2$, as indicated in Table 8.10 in Williams (2000). $CO_2$ capture rate is 0.104 kgC/kWh * (44/12) = 0.3810 $kgCO_2$/kWh (Table 8.10), or 105.9 $ktCO_2/PJ_e$. Capital cost includes cost of $CO_2$ compression and accounts for reduced net output due to power consumed for $CO_2$ compression. The cost given in Table 8.10 is increased to include $CO_2$ transport and sequestration costs (given as operating cost in Table 8.10, but which we have converted back to an equivalent capital cost.) Williams indicates annual non-fuel O&M costs of 4% of total capital cost. We assume half of this is fixed O&M and half is variable O&M. $SO_2$ emissions are from Table 8.1 in Williams (2000), but adjusted for the lower efficiency of the NGCC w/$CO_2$ capture relative to the 7H-based NGCC, on which the emissions given in Table 8.1 are based. Plant lifetime is assumed to be the same as for NGCC – air-cooled turbine.

## A20. ENG05: NG CC -El + F-T liquids

Technology characteristics are based on those for a plant designed by Bechtel (Choi *et al.*, 1997; Bechtel, 1998a) consuming 1141 MW of natural gas feedstock. Syngas from oxygen-autothermal reforming of the natural gas (with $CO_2$ recovered from raw syngas and recycled to reformer) is passed once through a liquid-phase Fischer-Tropsch synthesis reactor to produce 8815 barrels (48.5 TJ) per day of F-T liquids. Unconverted syngas is used to fire a gas turbine combined cycle producing 84.1 MW of electricity (GE Frame 7 gas turbine). The F-T liquids consist of naptha (2933 bbl/day, 14.6 TJ/day), distillate (5736 bbl/day, 33.3 TJ/day), and butanes (146 bbl/day, 0.6 TJ/day). Operating and maintenance costs are given by Choi, *et al.* (1997): administration and maintenance/insurance are considered fixed O&M costs; labor and chemicals/catalysts/water are considered variable O&M costs. Plant lifetime is assumed to be the same as for NGCC – air-cooled turbine.

## A21. ENG06: NG distributed fuel cell, combined heat and power production

Characteristics estimated for a 100 kW system using a proton exchange membrane fuel cell (Tom Kreutz, Princeton, personal communication, based on Kreutz and Ogden, 2000).

## A22. EPV01: Centralized, grid-connected solar photovoltaic electricity

Technology characteristics represent a ground-mounted grid-connected applications ranging from 100 kW to several MW. Current system costs were taken current US experience and from Turkenburg (2000). Projections for future costs were derived from Turkenburg (2000), Forest and Braun (1997), and RECS (1999). The technology was modeled with a fixed capacity utilization factor [CF] for summer,

intermediate and winter days as shown in the parameter table. The 30% peak coincidence factor was estimated to be representative of China as a whole.

## A23. EW02: Wind power plant - remote & trans

Technology characteristics are based on a 1.16 GW wind farm with a 500 km, 1 GW HVAC transmission line. Installed wind turbine costs for this very large farm was scaled form the local wind farm cost as (size in MW/50)^(-.1), and transmission line costs were estimated at $131 million from Lew, *et al.*(1998). Current system capital and O&M costs were taken from Lew, *et al.* (1998) and Turkenburg (2000). Significant Chinese manufacturing content was assumed to be achieved by 2010, and by 2030 the long-term potential cost was achieved. The 42% capacity factor was based on an optimization between wind farm size and tramsmission line size given in Lew, *et al.* (1998).

## A24. PBE01: Ethanol - cellulosic biomass

Characteristics of ethanol production from lignocellulosic biomass are based on Larson (1991). See also Larson (1993). Table A.9 in Larson (1991) gives costs and efficiencies for several different conversion systems. (All fuel values used here from the table have been converted from original HHV to LHV basis. Costs are given in 1990$ in the table. These have been brought to mid-1990s dollars by a multiplier of 1.1.) For the first two periods, the technology is SHF (separate hydrolysis and fermentation), where dilute sulfuric acid is used for hydrolysis. (This technology is in limited commercial use today.) The plant production capacity is 2 PJ/year ethanol, requiring 1212 tonnes of wood (dry basis) per day. The technology for the third, fourth, and fifth periods is SSF (simultaneous saccharification and fermentation), involving enzymes for the hydrolysis step. The plant outputs are 2 PJ/yr, 5 PJ/yr, and 24.8 PJ/yr, requiring wood (dry basis) in the amounts of 1013 t/day, 1745 t/day, and 9100 t/day. The technology in the 6$^{th}$ and subsequent periods is SSF that also incorporates fermentation of the xylose fraction of the biomass (which accounts for 30% to 60% of total fermentable sugars in biomass). Organisms capable of fermenting xylose have only been identified in the laboratory within the last decade or so. The scale of output in the 6$^{th}$ period is 5.9 PJ/yr (requiring 1738 t/day wood). For the 7$^{th}$ period and beyond, the scale is 11.5 PJ/yr (2714 t/day wood). Annual O&M costs are assumed to be 4% of capital investment. Plant lifetime is assumed to be the same as for coal process technologies.

## A25. PCG02: Coal - Towngas

Technology characteristics are based on those for a plant producing 400 MW of town gas, as indicated in Table 8.12 of Williams (2000). The plant uses a Destec oxygen-blown coal gasifier. Williams indicates annual non-fuel O&M costs of 4% of capital cost. $SO_2$ emissions are assumed to be zero (removed by gas cleanup system). Plant lifetime is assumed to be the same as for other coal facilities.

## A26. PCH01: Coal - H2 -- conventional technology

Technology characteristics are based on those for a plant producing 31.9 PJ/year of $H_2$ (LHV) from coal via oxygen-blown Shell gasifier, water-gas shift reactor, and conventional PSA $H_2$ separation (Williams *et al.*, 1995). Costs from Williams *et al.* have been multiplied by 1.1 to bring to mid-1990s values from 1991 original values. Assume annual O&M cost is 4% of capital cost. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.

## A27. PCH02: Coal - H2 with CO2 capture (CBM augmented)

This concept is based on Williams (1998), especially Tables 3 and 5. A mine-mouth facility produces $H_2$ from coal by oxygen-blown gasification (Shell gasifier), shift reaction, PSA separation.[2] The $CO_2$ is captured, compressed and injected into deep unminable coal seems, where it drives out coal-bed methane (CBM) that is captured and converted into additional $H_2$, with the separated $CO_2$ used for additional injection to further enhance CBM production. The CBM flows out at a rate of 9.2 GJ (LHV) per tonne

[2] This is conventional $H_2$ production technology (based on Williams, *et al.*, 1995).

$CO_2$ injected. Total $H_2$ production is 39.6 PJ/year, with coal accounting for 55% of this and CBM accounting for 45%. Since the CBM is internal to the overall system, it is not considered an energy input to the system. As a result, the apparent efficiency of $H_2$ production is greater than one.
Williams gives separate accounting of the $H_2$ production cost from coal and from CBM. The capital costs and O&M costs that we use represent an appropriately weighted average of these (55% from coal, 45% from CBM). The cost of the CBM is included as part of the total O&M cost of the system. (Williams indicates a cost of $2.25/GJ for CBM extracted by injection of $CO_2$.) Annual O&M cost is assumed to be 4% of capital plus the cost of the CBM. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.
The $CO_2$ capture rate (37.92 $ktCO_2/PJ_{H2}$) is based on Case Ia in Table 3 of Williams (see also Fig. 6). (Williams' numbers are based on coal with a carbon content of 22.99 kgC/GJ. We have made no adjustments for different carbon-content coal.) No value for the Markal $CO_2$ sequestration parameter {Carbon sequestered [OUT(MAT)p]} is specified in the inputs for this technology, because the $CO_2$ is not available for injection elsewhere (e.g., for enhanced oil recovery), as in the case with other carbon capturing technologies.

## A28. PCL02: Coal – Methanol

Technology characteristics are based on those for a plant producing 27.8 PJ/year of methanol (LHV) from coal via oxygen-blown Shell gasifier and conventional gas-phase methanol synthesis (Williams *et al.*, 1995). Costs from Williams *et al.* have been multiplied by 1.1 to bring to mid-1990s values from 1991 original values. Annual O&M cost is assumed to be 4% of initial capital cost. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.
For comparison, Sino-America Joint Research Group (1997) gives a capital investment for a methanol from coal facility with methanol production capacity of 1000 tonnes per day (7.3 PJ/year) of $45 per GJ/year. Indicated conversion efficiency is 60%, if an energy content of 23 GJ/t is assumed for coal.

## A29. PCL03: Coal - F-T liquids

Technology characteristics based on Bechtel (1998a), Case 2 (ZSM catalytic product upgrading), involving conversion of Illinois #6 coal to Fischer-Tropsch liquids. The plant design includes a Shell oxygen-blown gasifier and liquid-phase F-T synthesis, with recycle of uncoverted syngas. The plant has a coal consumption capacity of 468 TJ/day (16886 metric t/day) and produces 3621 bbl/day (13.7 TJ/d) of propane/butane, 31255 bbl/d (156.2 TJ/d) of F-T gasoline, and 15858 bbl/d (92.4 TJ/d) of F-T diesel. The plant consumes 4.8 kWh of electricity per GJ F-T liquids produced. (No efficiency penalty is included for this, but the electricity cost is included in the O&M cost estimate.) The process includes a $CO_2$ separation downstream of the synthesis reactor (to improve product recovery and achieve proper C/H ratio in recycle loop). The plant design calls for venting of the $CO_2$ at a rate of 13.9 million $m^3$/day, or 52.9 $m^3/GJ_{F\text{-}T\ product}$. The $CO_2$ rate is from Bechtel (1993a), which gives additional details to those found in Bechtel (1998a).
$SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.
For comparison, Sino-America Joint Research Group (1997) gives a capital investment for a facility producing 1834 tonnes per day of F-T gasoline from coal to be $54.4 per GJ/year. (Conversion efficiency is 45%, if a coal energy content of 23 GJ/t is assumed.)

## A30. PCL03S: Coal - F-T liquids, with CO2 capture/sequestration

Technology characteristics based on Bechtel (1998a), Case 2 (ZSM catalytic product upgrading), involving conversion of Illinois #6 coal to Fischer-Tropsch liquids. The plant design includes a Shell oxygen-blown gasifier and liquid-phase F-T synthesis, with recycle of uncoverted syngas. The plant has a coal consumption capacity of 468 TJ/day (16886 metric t/day) and produces 3621 bbl/day (13.7 TJ/d) of propane/butane, 31255 bbl/d (156.2 TJ/d) of F-T gasoline, and 15858 bbl/d (92.4 TJ/d) of F-T diesel. The plant consumes 4.8 kWh of electricity per GJ F-T liquids produced. (No efficiency penalty is included

for this, but the electricity cost is included in the O&M cost estimate.) The process includes a $CO_2$ separation downstream of the synthesis reactor (to improve product recovery and achieve proper C/H ratio in recycle loop). The $CO_2$ is available at 1.3 bar (Bechtel, 1993a). The plant design calls for venting of the $CO_2$ at a rate of 13.9 million $m^3$/day, or 52.9 $m^3/GJ_{F\text{-}T\ product}$ (97.96 $kgCO_2/GJ_{F\text{-}T}$). The $CO_2$ rate is from Bechtel (1993a), which gives additional details to those found in Bechtel (1998a). The electricity required to compress this much $CO_2$ from 1.3 bar to 100 bar is 85 MW (based on Blok *et al.*, 1997), or 7.8 kWh per $GJ_{F\text{-}T\ product}$.
We estimate the added cost for carbon capture (see general notes above) to be $364 million. We also include added electricity cost for $CO_2$ compression of (7.8 $kWh/GJ_{F\text{-}T}$ * 5 c/kWh = ) $0.63/$GJ_{F\text{-}T\ product}$. As in other cases described above, an additional capital cost ($282 million) is included for transportation and sequestration corresponding to $5/t$CO_2$.
Annual O&M costs are assumed to be 4% of initial capital cost plus $0.63/GJ for the electricity to compress the $CO_2$. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.

## A31. PCL04: Coal – DME

Technology characteristics are from Adachi *et al.* (2000) for a plant producing 26.3 PJ/year of DME. The capital cost given in the Adachi paper appears to be too low by 2 orders of magnitude (probably a typo). For investment cost, we have used 100x the capital cost given by Adachi. Annual O&M costs are assumed to be 4% of initial capital cost. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other coal facilities.

## A32. PNG01: NG – Methanol

Technology characteristics are based on those for a plant with a production capacity of 2012 tonnes/day (14.6 PJ/yr, LHV) of methanol via steam reforming of natural gas and conventional gas-phase methanol synthesis (Williams *et al.*, 1995). Costs from Williams *et al.* have been multiplied by 1.1 to bring to mid-1990s values from 1991 original values. Annual O&M cost is assumed to be 4% of capital. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other natural gas facilities.
For comparison, Sino-American Joint Research Group (1997) gives a capital investment for a methanol from coal-bed gas (assumed to be methane) facility with methanol production capacity of 1000 tonnes per day of $13.9 per GJ/year. Indicated conversion efficiency is 82%.

## A33. PNG02: NG - F-T liquids

Technology characteristics based on Choi *et al.* (1996). See also Bechtel (1998a), Case 7. The plant design includes a mix of steam reforming and oxygen partial-oxidation reforming of natural gas followed by liquid-phase F-T synthesis, $CO_2$ removal, and $H_2$ recovery from unconverted syngas for use in hydroprocessing and recycle to the synthesis reactor. The remaining fuel value in the unconverted syngas is used to make a small amount of electricity (24.7 MW net export). We ignore the electricity output for purposes of modeling. The plant has a natural gas consumption capacity of 406 TJ/day and produces 1360 bbl/day (4.9 TJ/d) of propane/butane, 17000 bbl/d (152 TJ/d) of F-T gasoline, and 26200 bbl/d (86.4 TJ/d) of F-T diesel. The process includes a $CO_2$ separation downstream of the synthesis reactor (to improve product recovery and achieve proper C/H ratio in recycle loop). The plant design calls for venting of the $CO_2$ at a rate of 66500 $m^3$/hour, or 6.52 $m^3/GJ_{F\text{-}T\ product}$. The $CO_2$ rate is from Bechtel (1996), which gives additional details to those found in Bechtel (1998a). Annual O&M cost is assumed to be 4% of capital. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other natural gas facilities.

## A34. PNG02S: NG - F-T liquids, with CO2 capture/sequestration

Technology characteristics based on Choi *et al.* (1996). See also Bechtel (1998a), Case 7. The plant design includes a mix of steam reforming and oxygen partial-oxidation reforming of natural gas followed

by liquid-phase F-T synthesis, $CO_2$ removal, and $H_2$ recovery from unconverted syngas for use in hydroprocessing and recycle to the synthesis reactor. The remaining fuel value in the unconverted syngas is used to make a small amount of electricity (24.7 MW net export). The output of electricity is ignored for purposes of modeling. The plant has a natural gas consumption capacity of 406 TJ/day and produces 1360 bbl/day (4.9 TJ/d) of propane/butane, 17000 bbl/d (152 TJ/d) of F-T gasoline, and 26200 bbl/d (86.4 TJ/d) of F-T diesel. The process includes a $CO_2$ separation downstream of the synthesis reactor (to improve product recovery and achieve proper C/H ratio in recycle loop). The plant design calls for venting of the $CO_2$ at a rate of 66500 $m^3$/hour, or 6.52 $m^3/GJ_{F\text{-}T\ product}$ (12.07 $kgCO_2/GJ_{F\text{-}T}$) The $CO_2$ rate is from Bechtel, (1996), which gives additional details to those found in Choi, *et al.* (1996) and in Bechtel (1998a). The $CO_2$ is available at 18 bar. Compressing to 100 bar for transport would require less than 10 MW of electricity (528 $kJ_e/m^3CO_2$ * 6.52 $m^3/GJ_{F\text{-}T}$ * 243,300 $GJ_{F\text{-}T}$/day / (24*3600). This requirement is ignored as an operating cost, since the 25 MW net export of electricity (also ignored) would be more than sufficient to provide this.
The added cost for carbon capture (see general notes above) is $42 million. As in other cases described above, an additional capital cost ($32 million) is included for transportation and sequestration corresponding to $5/t$CO_2$.
Annual O&M costs are assumed to be 4% of capital cost. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other natural gas facilities.

## A35. PNG03: NG - H2

Technology characteristics are based on those for a plant producing 16.2 PJ/year of $H_2$ (LHV) from natural gas via steam reforming, water-gas shift reactor, and conventional PSA $H_2$ separation (Williams *et al.*, 1995). Costs from Williams *et al.* have been multiplied by 1.1 to bring to mid-1990s values from 1991 original values. Annual O&M costs are assumed to be 4% of capital investment. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other natural gas facilities.

## A36. PNG03S: NG - H2 with CO2 capture

Technology characteristics are based on those for a plant producing 84.5 PJ/year of $H_2$ (LHV) from natural gas via reforming, water-gas shift reactor, and PSA $H_2$–$CO_2$ separation (Blok *et al.*, 1997). Capital costs are given for the complete $H_2$ production system plus capturing 70% of the $CO_2$, compressing it to 80 bar, transporting it by pipeline and injecting into a depleted natural gas field for sequestration. Annual non-fuel O&M costs are given by Blok, *et al.* ($457 million). This is 30% of capital investment, which is excessive. We assume 4%. The $CO_2$ capture rate (Fig. 1B in Blok *et al.*) is 39.05 $kt/PJ_{H2}$. This represents about 70% capture compared to a no-capture plant.

## A37. PNG04: NG – DME

Based on performance and cost estimates of Hansen, *et al.* (1995) for natural gas conversion to 2500 metric tonnes per day of methanol equivalent as DME. (Methanol-equivalent of DME is 2 times actual DME, since two moles of methanol ($CH_3OH$) can be made from one mole of DME – $CH_3OCH_3$.). The plant uses oxygen-fed autothermal reforming of the natural gas and gas-phase synthesis of DME, with recycle of the unconverted syngas to the synthesis reactor. Hansen, *et al.* indicate that the capital cost for such a facility is 96% of the capital cost for a methanol plant of same methanol-equivalent capacity. The plant described by Williams, *et al.* (1995), which we used as the basis for cost estimate for NG-methanol, has a production capacity of 2000 t/day methanol. The capital cost per unit methanol output for the NG-methanol plant is multiplied by 0.96 to arrive at the unit capital cost for the NG-DME plant. Annual O&M costs are assumed to be 4% of capital cost. $SO_2$ emissions are assumed to be zero. Plant lifetime is assumed to be the same as for other natural gas facilities.

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