Technology Data for the Indonesian Power Sector

Catalogue for Generation and Storage of Electricity

December 2017

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CONTENT

FOREWORD

Today, we see that innovations and technology improvements within renewable energy are taking place at a very high pace. Long term energy planning is very dependent on the best estimate with regard to price and performance of future energy producing technologies. The objective of this technology catalogue is to estimate exactly that. Having good understanding of technologies in terms of price and performance is the key to good energy planning.

Due to the multi-stakeholder involvement in the data collection process, the technology catalogue contains data that have been scrutinised and discussed by a broad range of relevant stakeholders including PLN, DJK, MEMR and NEC. This is essential because the main objective is to have a technology catalogue that is well anchored amongst all stakeholders and where all stakeholders have agreed that the published data are the best estimate based on current knowledge.

Further, the technology catalogue will also assist the long-term energy modelling in Indonesia and support government institutions, private energy companies, think tanks and others in developing relevant policies and business strategies to achieve the government's long-term Renewable Energy and Energy Efficiency targets and not least to increase electrification rate in Indonesia.

The technology catalogue has been developed by the Secretariat General of the National Energy Council in close collaboration with the Danish Embassy and the Danish Energy Agency – supported by BPPT Engineering and Ea Energy Analyses. The technology catalogue is a dynamic tool by nature that requires continuous update and the National Energy Council will strive to update the catalogue on a regular basis.

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Secretary General, National Energy Council

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METHODOLOGY

Introduction to methodology

The technologies described in this catalogue cover both very mature technologies and technologies which are expected to improve significantly over the coming decades, both with respect to performance and cost. This implies that the price and performance of some technologies may be estimated with a rather high level of certainty whereas in the case of other technologies both cost and performance today as well as in the future is associated with a high level of uncertainty. All technologies have been grouped within one of four categories of technological development (described in section about Research and development) indicating their technological progress, their future development perspectives and the uncertainty related to the projection of cost and performance data.

The boundary for both cost and performance data are the generation assets plus the infrastructure required to deliver the energy to the main grid. For electricity, this is the nearest land-based substation of the transmission grid. This implies that a MW of electricity represents the net electricity delivered, i.e. the gross generation minus the auxiliary electricity consumed at the plant. Hence, efficiencies are also net efficiencies.

Unless otherwise stated, the thermal technologies in the catalogue are assumed to be designed for and operating for approx. 6000 full-load hours of generation annually (capacity factor of 70%). Some of the exceptions are municipal solid waste generation facilities and geothermal power plants, which are designed for continuous operation, i.e. approximately 8000 full-load hours annually (capacity factor of 90%).

Each technology is described by a separate technology sheet, following the format explained below.

Qualitative description

The qualitative description describes the key characteristic of the technology as concise as possible. The following paragraphs are included if found relevant for the technology.

Technology description
Brief description for non-engineers of how the technology works and for which purpose.

Input
The main raw materials, primarily fuels, consumed by the technology.

Output
The output of the technologies in the catalogue is electricity. Other output such as process heat are mentioned here.

Typical capacities
The stated capacities are for a single ‘engine’ (e.g. a single wind turbine or a single gas turbine), as well as for the total power plant consisting of a multitude of ‘engines’ such as a wind farm. The total power plant capacity should be that of a typical installation in Indonesia.

Ramping configurations and other power system services
Brief description of ramping configurations for electricity generating technologies, i.e. what are the part-load characteristics, how fast can they start up, and how quickly are they able to respond to demand changes (ramping)?

Advantages/disadvantages
Specific advantages and disadvantages relative to equivalent technologies. Generic advantages are ignored; for example, that renewable energy technologies mitigate climate risk and enhance security of supply.

Environment
Particular environmental characteristics are mentioned, e.g. special emissions or the main ecological footprints.

Employment
Description of the employment requirements of the technology in the manufacturing and installation process as well as during operation. This will be done both by examples and by listing the requirements in the legal regulation for local content (from Minister Decree or Order No. 54/M-IND/PER/3/2012 and No. 05/M-IND/PER/2/2017). It is compulsory for projects owned or funded by government or government owned companies to follow these regulations. The table below summarizes the regulation. By local content requirement is meant the amount of work and/or resources that must be applied in Indonesia.

Summarizing the local requirement regulation.

Type	Capacity	Local Content Requirement (%)		
		Goods (minimum)	Services	Combined Goods and Services (minimum)
Steam Power Plant	Up to 15 MW	67.95	96.31	70.79
	15 – 25 MW	45.36	91.99	49.09
	25 – 100 MW	40.85	88.07	44.14
	100 – 600 MW	38.00	71.33	40.00
	> 600 MW	36.10	71.33	38.21
Hydro Power Plant	Up to 15 MW	64.20	86.06	70.76
	15 – 50 MW	49.84	55.54	51.60
	50 – 150 MW	48.11	51.10	49.00
	> 150 MW	47.82	46.98	47.60
Geothermal Power Plant	Up to 15 MW	31.30	89.18	42.00
	5 – 10 MW	21.00	82.30	40.45
	10 – 60 MW	15.70	74.10	33.24
	60 – 110 MW	16.30	60.10	29.21
	> 110 MW	16.00	58.40	28.95
Gas Power Plant	Up to 100 MW	43.69	96.31	48.96

Gas Combined Cycle Power Plant	Up to 50 MW	40.00	71.53	47.88
	50 – 100 MW	35.71	71.53	40.00
	100 – 300 MW	30.67	71.53	34.76
	> 300 MW	25.63	71.53	30.22
Solar PV Power Plant	Decentralized off-grid	39.87	100.00	45.90
	Centralized off-grid	37.47	100.00	43.72
	Centralized on-grid	34.09	100.00	40.68

Research and development

The section lists the most important challenges from a research and development perspective. Particularly Indonesian research and development perspectives is highlighted if relevant.

The section also describes how mature the technology is.

The first year of the projection is 2020 (base year). In this catalogue, it is expected that cost reductions and improvements of performance are realized in the future.

This section accounts for the assumptions underlying the improvements assumed in the data sheet for the years 2030 and 2050.

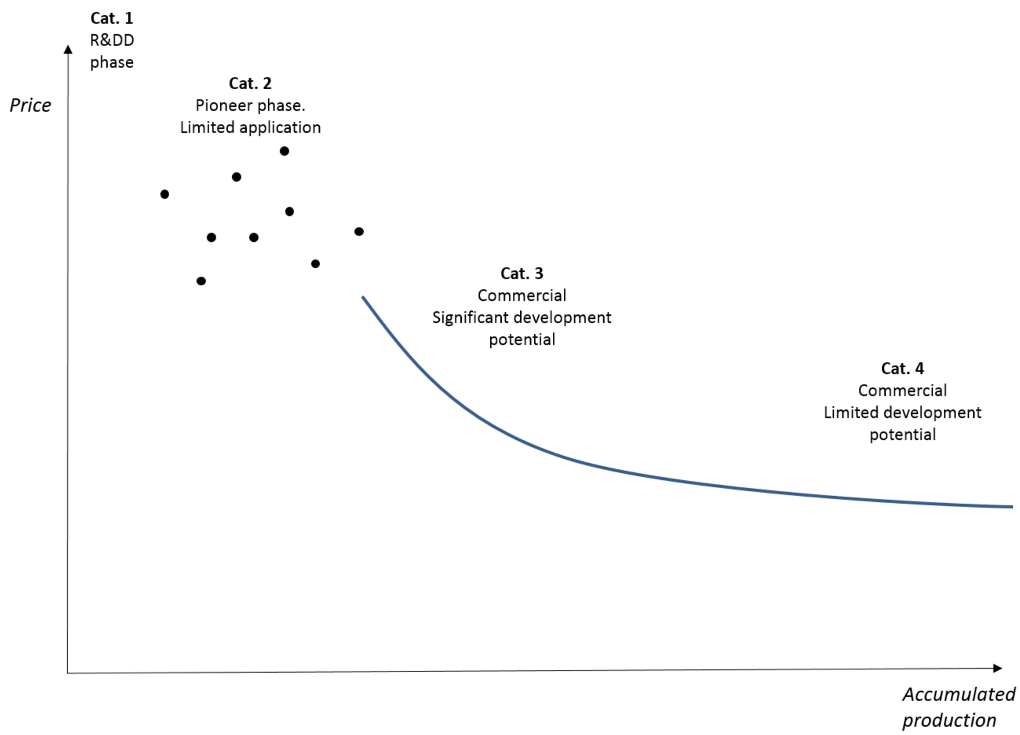
The potential for improving technologies is linked to the level of technological maturity. Therefore, this section also includes a description of the commercial and technological progress of the technology. The technologies are categorized within one of the following four levels of technological maturity.

Category 1. Technologies that are still in the *research and development phase*. The uncertainty related to price and performance today and in the future, is very significant.

Category 2. Technologies in the *pioneer phase*. Through demonstration facilities or semi-commercial plants, it has been proven that the technology works. Due to the limited application, the price and performance is still attached with high uncertainty, since development and customization is still needed. (e.g. gasification of biomass).

Category 3. *Commercial technologies with moderate deployment* so far. Price and performance of the technology today is well known. These technologies are deemed to have a significant development potential and therefore there is a considerable level of uncertainty related to future price and performance (e.g. offshore wind turbines)

Category 4. *Commercial technologies, with large deployment* so far. Price and performance of the technology today is well known, and normally only incremental improvements would be expected. Therefore, the future price and performance may also be projected with a fairly high level of certainty (e.g. coal power, gas turbine).



Technological development phases. Correlation between accumulated production volume (MW) and price.

Examples of current projects
Recent technological innovations in full-scale commercial operation should be mentioned, preferably with references and links to further information. This is not necessarily a Best Available Technology (BAT), but more on an indication of the standard that are currently being commissioned.

References
All descriptions shall have a reference, which is listed and emphasized in the qualitative description.

Quantitative description

To enable comparative analyses between different technologies it is imperative that data is actually comparable. As an example, economic data is stated in the same price level and value added taxes (VAT) or other taxes are excluded. The reason for this is that the technology catalogue should reflect the socio-economic cost for the Indonesian society. In this context taxes do not represent an actual cost but rather a transfer of capital between Indonesian stakeholders, the project developer and the government. Also, it is essential that data be given for the same years. Year 2020 is the base for the present status of the technologies, i.e. best available technology at the point of commissioning.

All costs are stated in U.S. dollars (USD), price year 2016. When converting costs from a year X to USD2016 the following approach is recommended:

1. If the cost is stated in IDR, convert to USD using the exchange rate for year X (first table below).

2. Then convert from USD in year X to USD in 2016 using the relationship between the US Producer Price Index for "Engine, Turbine, and Power Transmission Equipment Manufacturing" of year X and 2016 (second table below).

The yearly average exchange rate between IDR and USD (source: MEMR, 2017, Handbook of energy & economic statistics of Indonesia)

Year	**IDR to USD**
2007	9,419
2008	10,950
2009	9,400
2010	8,991
2011	9,068
2012	9,670
2013	12,189
2014	12,440
2015	13,795
2016	13,436

US Producer Price Index for "Engine, Turbine, and Power Transmission Equipment Manufacturing". This industry comprises establishments primarily engaged in manufacturing turbines, power transmission equipment, and internal combustion engines (except automotive gasoline and aircraft), "North American Industry Classification System, United States, 2017" p. 258 and US Bureau of Labor Statistics, Series Id: PCU333611333611)

Year	**Producer Price Index**
2007	168,9
2008	188,6
2009	209,9
2010	210,4
2011	212,5
2012	211,1
2013	215,0
2014	220,6
2015	221,1
2016	220,6

The construction time, which is also specified in the data sheet, represents the time between the financial when closure is achieved, i.e. when financing is secured, and all permits are at hand, and the point of commissioning.

Below is a typical datasheet, containing all parameters used to describe the specific technologies. The datasheet consists of a generic part, which is identical for groups of similar technologies (thermal power plants, non-thermal power plants and heat generation technologies) and a technology specific part, containing information, which is only relevant for the specific technology. The generic technology part is made to allow for an easy comparison of technologies.

Each cell in the data sheet should only contain one number, which is the central estimate for the specific technology, i.e. no range indications. Uncertainties related to the figures should be stated in the columns called *uncertainty*. To keep the data sheet simple, the level of uncertainty is only specified for years 2020 and 2050. The level of uncertainty is illustrated by providing a lower and higher bound indicating a confidence interval of 90%. The uncertainty it related to the 'market standard' technology; in other words, the uncertainty interval does not represent the product range (for example a product with lower efficiency at a lower price or vice versa). For certain technologies, the catalogue covers a product range, this is for example the case for coal power, where both sub-critical, super-critical and ultra-super critical power plants are represented. The reason is, that for coal power it is not obvious, which type of product is the market standard in Indonesia.

The level of uncertainty needs only to be stated for the most critical figures such as for example investment costs and efficiencies.

All data in the datasheets are referenced by a number in the utmost right column (Ref), referring to sources specified below the table.

Before using the data, please note that essential information may be found in the notes below the table.

The generic parts of the datasheets for thermal power plants, non-thermal power plants and heat generation technologies are presented below:

Technology	Name of technology								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)									
Generating capacity for total power plant (MWe)									
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average									
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)									
Construction time (years)									
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (g per GJ fuel)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)									
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)									
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1

2

Notes:

A

B

Energy/technical data

Generating capacity

The capacity is stated for both a single ‘engine’, e.g. a single wind turbine or gas engine, and for the total power plant, for example a wind farm or gas fired power plant consisting of multiple gas engines. The sizes of ‘engines’ and the total power plant should represent typical power plants. Factors for scaling data in the catalogue to other plant sizes than those stated are presented later in this methodology section.

The capacity is given as net generation capacity in continuous operation, i.e. gross capacity (output from generator) minus own consumption (house load), equal to capacity delivered to the grid.

The unit MW is used for electric generation capacity, whereas the unit MJ/s is used for fuel consumption.

This describes the relevant product range in capacity (MW), for example 200-1000 MW for a new coal-fired power plant. It should be stressed that data in the sheet is based on the typical capacity, for example 600 MW for a coal-fired power plant. When deviations from the typical capacity are made, economy of scale effects need to be considered (see the section about investment cost).

Energy efficiencies

Efficiencies for all thermal plants are expressed in percentage at lower calorific heat value (lower heating value or net heating value) at ambient conditions in Indonesia, considering an average air temperature of approximately 28 °C.

The electric efficiency of thermal power plants equals the total delivery of electricity to the grid divided by the fuel consumption. Two efficiencies are stated: the nameplate efficiency as stated by the supplier and the expected typical annual efficiency.

Often, the electricity efficiency is decreasing slightly during the operating life of a thermal power plant. This degradation is not reflected in the stated data. As a rule of thumb, you may deduct 2.5 – 3.5% points during the lifetime (e.g. from 40% to 37%).

Forced and planned outage

Forced outage is defined as number of weighted forced outage hours divided by the sum of forced outage hours and operation hours. The weighted forced outage hours are the hours caused by unplanned outages, weighted according to how much capacity was out.

Forced outage is given in per cent, while planned outage (for example due to renovations) is given in weeks per year.

Technical lifetime

The technical lifetime is the expected time for which an energy plant can be operated within, or acceptably close to, its original performance specifications, provided that normal operation and maintenance takes place. During this lifetime, some performance parameters may degrade gradually but still stay within acceptable limits. For instance, power plant efficiencies often decrease slightly (few percent) over the years, and operation and maintenance costs increase due to wear and degradation of components and systems. At the end of the technical lifetime, the frequency of unforeseen operational problems and risk of breakdowns is expected to lead to unacceptably low availability and/or high operations and maintenance costs. At this time, the plant would be decommissioned or undergo a lifetime extension, implying a major renovation of components and systems as required to make the plant suitable for a new period of continued operation.

The technical lifetime stated in this catalogue is a theoretical value inherent to each technology, based on experience. In real life, specific plants of similar technology may operate for shorter or longer times. The strategy for operation and maintenance, e.g. the number of operation hours, start-ups, and the reinvestments made over the years, will largely influence the actual lifetime.

Construction time
Time from final investment decision (FID) until commissioning completed (start of commercial operation), expressed in years.

Space requirement
If relevant, space requirement is specified (1000 m^2 per MW). The space requirements may among other things be used to calculate the rent of land, which is not included in the financial since the cost item depends on the specific location of the plant.

Average annual capacity
For non-thermal power generation technologies, a typical average annual capacity factor is presented. The average annual capacity factor represents the average annual net generation divided by the theoretical annual net generation, if the plant were operating at full capacity all year round. The equivalent full-load hours per year is determined by multiplying the capacity factor by 8760 hours, the total number of hours in a year.

The capacity factor for technologies like solar, wind and hydropower is very site specific. In these cases, the typical capacity factor is supplemented with additional information, for example maps or tables, explaining how the capacity will vary depending on the geographic location of the power plant. This information is normally integrated in the brief technology description.

The theoretical capacity factor represents the production realised, assuming no planned or forced outages. The realised full-loads considers planned and forced outage.

Ramping configuration

The electricity ramping configuration of the technologies is described by five parameters:

A. Ramping (% per minute)
B. Minimum load (per cent of full load).
C. Warm start up time, (hours)
D. Cold, start-up time, (hours)

For several technologies, these parameters are not relevant, e.g. if the technology can ramp to full load instantly in on/off-mode.

Parameter A are spinning reserves; i.e. the ability to ramp up and down when the technology is already in operation.

Parameter B is the minimum load from which the boiler can operate.

Parameter C, the warm start-up time, used for boiler technologies, is defined as the time for starting, from a starting point where the water temperature in the evaporator is above 100ºC, which means that the boiler is pressurized.

Parameter D. The cold start-up time used for boiler technologies is defined as the time it takes to reach operating temperature and pressure and start production from a state were the boiler is at ambient temperature and pressure.

Environment

The plants should be designed to comply with the regulation that is currently in place in Indonesia and planned to be implemented within the 2020 time horizon.

CO_2 emission values are not stated, but these may be calculated by the reader of the catalogue by combining fuel data with technology efficiency data.

Where relevant, for example for gas turbines, emissions of methane (CH_4) and Nitrous oxide (N_2O), which are both potent greenhouse gas, should be stated in grams per GJ fuel.

Emissions of particulate matter are expressed as PM 2.5 in gram per GJ fuel.

SO_x emissions are calculated based on the following sulphur contents of fuels:

	Coal	Fuel oil	Gas oil	Natural gas	Wood	Waste	Biogas
Sulphur (kg/GJ)	0.35	0.25	0.07	0.00	0.00	0.27	0.00

The Sulphur content can vary for difference kinds of coal products. The Sulphur content of coal is calculated from a maximum sulphur weight content of 0.8%. From Rich Coal Indonesia (http://www.richcoalindonesia.com/?page=specifications).

For technologies, where desulphurization equipment is employed (typically large power plants), the degree of desulphurization is stated in percentage terms.

NO_x emissions equals NO_2 + NO, where NO is converted to NO_2 in weight-equivalents. NO_x emissions are also stated in grams per GJ fuel.

Financial data

Financial data are all in USD fixed prices, price-level 2016 and exclude value added taxes (VAT) or other taxes.

For projection of future financial costs there are three overall approaches; Engineering bottom-up, Delphi-survey, and Learning curves. This catalogue uses the learning curve approach. The reason is, that this method has proved historically robust and that it is possible to estimate learning rates for most technologies. Ea Energy Analyses have prepared a separate note, "Forecasting cost of electricity production technologies", on the approach used in this catalogue, which is attached in appendix.

Investment costs

The investment cost or initial cost is often reported on a normalized basis, e.g. cost per MW. The nominal cost is the total investment cost divided by the net generating capacity, i.e. the capacity as seen from the grid.

If possible, the investment cost is divided into equipment cost and installation cost. Equipment cost covers the plant itself, including environmental facilities, whereas installation costs covers buildings, grid connection and installation of equipment.

Different organizations employ different systems of accounts to specify the elements of an investment cost estimate. Since there is no universally employed nomenclature, investment costs do not always include the same items. Actually, most reference documents do not state the exact cost elements, thus introducing an unavoidable uncertainty that affects the validity of cost comparisons. Also, many studies fail to report the year (price level) of a cost estimate.

In this report, the intension is that investment cost shall include all physical equipment, typically called the engineering, procurement and construction (EPC) price or the *overnight cost*. Connection costs are included, but reinforcements are not included. It is here an assumption that the connection to the grid is within a reasonable distance.

The rent or buying of land is *not* included, but may be assessed based on the space requirements specified under the energy/technical data. The reason for the land not being directly included, is that land, for the most part, do not lose its value. It can therefore be sold again after the power plant has fulfilled its purpose and been decommissioned.

The owners' predevelopment costs (administration, consultancy, project management, site preparation, and approvals by authorities) and interest during construction are not included. The cost to dismantle decommissioned plants is also not included. Decommissioning costs may be offset by the residual value of the assets.

Cost of grid expansion
As mentioned the costs of grid connection is included, however possible costs of grid expansion from adding a new electricity generator to the grid are not included in the presented data.

Business cycles
Costs of energy equipment surged dramatically in 2007-2008. The trend was general and global. One example is combined cycle gas turbines (CCGT): "*After a decade of cycling between $400 and $600 a kW installed EPC prices for CCGT increased sharply in 2007 and 2008 to peak at around $1250/kW in Q3:2008. This peak reflected tender prices: no actual transactions were done at these prices."* (Global CCS Institute). Such unprecedented variations obviously make it difficult to benchmark data from the recent years, but a catalogue as the present cannot be produced without using a number of different sources from different years. The reader is urged to bear this in mind, when comparing the costs of different technologies.

Economy of scale
The per unit cost of larger power plants are usually less than that of smaller plants. This is called the 'economy of scale'. The proportionality was examined in some detail in the article "Economy of Scale in Power Plants" in the August 1977 issue of Power Engineering Magazine (p. 51). The basic equation is:

$$\frac{C_1}{C_2} = \left(\frac{P_1}{P_2}\right)^a$$

Where:
C_1 = Investment cost of plant 1 (e.g. in million US$)
C_2 = Investment cost of plant 2
P_1 = Power generation capacity of plant 1 (e.g. in MW)
P_2 = Power generation capacity of plant 2
a = Proportionality factor

For many years, the proportionality factor averaged about 0.6, but extended project schedules may cause the factor to increase. However, used with caution, this rule may be applied to convert data in this catalogue to other plant sizes than those stated. It is important that the plants are essentially identical in construction technique, design, and time frame and that the only significant difference is size.

For very large-scale plants, like large coal power plants, we may have reached a practical limit, since very few investors are willing to add increments of 1000 MW or above. Instead, by building multiple unit at the same spot can provide sufficient savings through allowing sharing of balance of plant equipment and support infrastructure. Typically, about 15% savings in investment cost per MW can be achieved for gas combined cycle and big steam power plant from a twin unit arrangement versus a single unit ("Projected Costs of Generating Electricity", IEA, 2010). The financial data in this catalogue are all for single unit plants (except for wind farms and solar PV), so one may deduct 15% from the investment costs, if very large plants are being considered.
Unless otherwise stated the reader of the catalogue may apply a proportionality factor of 0.6 to determine the investment cost of plants of higher or lower capacity than the typical capacity specified for the technology. For each technology, the relevant product range (capacity) is specified.

Operation and maintenance (O&M) costs.
The fixed share of O&M is calculated as cost per generating capacity per year ($/MW/year), where the generating capacity is the one defined at the beginning of this chapter and stated in the tables. It includes all costs, which are independent of how many hours the plant is operated, e.g. administration, operational staff, payments for O&M service agreements, network or system charges, property tax, and insurance. Any necessary reinvestments to keep the plant operating within the technical lifetime are also included, whereas reinvestments to extend the life beyond the technical life time are excluded. Reinvestments are discounted at 4% annual discount rate in real terms. The cost of reinvestments to extend the lifetime of the plants may be mentioned in a note if data is available.

The variable O&M costs ($/MWh) include consumption of auxiliary materials (water, lubricants, fuel additives), treatment and disposal of residuals, spare parts and output related repair and maintenance (however not costs covered by guarantees and insurances). Planned and unplanned maintenance costs may fall under fixed costs (e.g. scheduled yearly maintenance works) or variable costs (e.g. works depending on actual operating time), and are split accordingly.

Fuel costs are not included.

It should be noticed that O&M costs often develop over time. The stated O&M costs are therefore average costs during the entire lifetime.

SUMMARY OF KEY TECHNOLOGY DATA

Power generation technologies

Technology	**Year**	**Plant size** MWe	**Investment** M$/MWe	**Fixed O&M** $/MWe/year	**Var. O&M** $/MWh	**Electr. efficiency** %	**Capacity factor** (*only non-dispatc.*)
Geothermal - small	2020	10	4.50	20,000	0.37	10	80
	2030	10	4.20	18,500	0.34	11	80
	2050	10	3.80	16,900	0.31	12	80
Geothermal - large	2020	55	3.50	18,000	0.25	15	80
	2030	55	3.20	16,700	0.23	16	80
	2050	55	2.90	15,200	0.21	17	80
Hydro - mini	2020	5	2.60	53,000	0.50	-	80
	2030	5	2.60	50,400	0.48	-	80
	2050	5	2.60	47,200	0.45	-	80
Hydro - medium	2020	50	2.20	41,900	0.50	-	80
	2030	50	2.20	39,800	0.48	-	80
	2050	50	2.20	37,300	0.45	-	80
Hydro - large	2020	150	2.00	37,700	0.65	-	40
	2030	150	2.00	35,800	0.62	-	40
	2050	150	2.00	33,600	0.58	-	40
Solar PV - large	2020	10	0.83	15,000	-	-	20
	2030	10	0.61	12,500	-	-	20
	2050	10	0.45	10,500	-	-	21
Wind - small onshore	2020	0.85	4.00	73,200	-	-	34
	2030	0.90	3.48	63,700	-	-	35
	2050	0.95	2.96	54,200	-	-	37
Wind - large onshore	2020	3.5	1.50	60,000	-	-	34
	2030	4.0	1.31	5,200	-	-	35
	2050	5.0	1.11	44,400	-	-	37
Wind - offshore	2020	8	3.50	72,600	-	-	48
	2030	10	3.05	64,700	-	-	49
	2050	12	3.59	55,000	-	-	50
Coal - sub crit.	2020	150	1.65	45,250	0.13	34	-
	2030	150	1.60	43,900	0.12	35	-
	2050	150	1.55	42,500	0.12	36	-
Coal - super crit.	2020	600	1.40	41,200	0.12	37	-
	2030	600	1.36	39,900	0.12	38	-
	2050	600	1.32	38,700	0.11	39	-
Coal - ultra-super crit.	2020	1000	1.52	56,600	0.11	42	-
	2030	1000	1.48	54,900	0.11	43	-
	2050	1000	1.43	53,200	0.10	44	-
Biomass - small	2020	25	1.70	47,600	3.00	31	-
	2030	25	1.60	43,800	2.80	31	-
	2050	25	1.40	37,100	2.40	31	-
Waste - incineration	2020	22	8.70	243,700	24.10	28	-
	2030	22	8.10	224,800	23.40	29	-
	2050	22	7.20	193,500	22.60	29	-
Waste - landfill gas	2020	1	2.50	125,000	3.00	34	-
	2030	1	2.50	125,000	3.00	34	-
	2050	1	2.50	125,000	3.00	34	-
Biogas - small	2020	1	2.80	97,000	0.11	34	-
	2030	1	2.60	89,200	0.10	34	-
	2050	1	2.20	77,600	0.10	34	-

Gas - SCGT	2020	50	0.77	23,200	0.11	34	-
	2030	50	0.73	22,500	0.10	36	-
	2050	50	0.68	21,800	0.10	40	-
Gas - CCGT	2020	600	0.75	23,200	0.13	56	-
	2030	600	0.71	22,500	0.13	59	-
	2050	600	0.66	21,800	0.12	60	-
Diesel - engine	2020	20	0.80	8,000	6.40	46	-
	2030	20	0.80	8,000	6.00	47	-
	2050	20	0.78	7,800	5.80	48	-

Power storage technologies

Technology	**Year**	**Plant size** MWe	**Investment** M$/MWh	**Fixed O&M** $/MWh/year	**Var. O&M** $/MWh	**Electr. efficiency** %	**Capacity factor** (*only non-dispatc.*)
Storage - pump. hydro	2020	250	0.02	200	1.30	80	-
	2030	250	0.02	200	1.30	80	-
	2050	250	0.02	200	1.30	80	-
Storage - Li-ion battery	2020	10	0.25	7,000	-	88	-
	2030	10	0.14	7,000	-	88	-
	2050	10	0.13	7,000	-	88	-

1. GEOTHERMAL POWER PLANT

Brief technology description

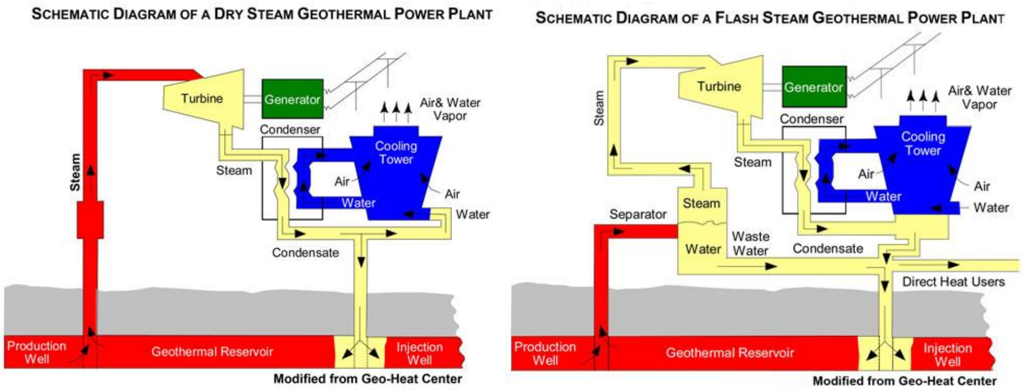
Geothermal resources in Indonesia are mainly classified as hydrothermal geothermal systems with high temperatures (> 225°C). Only a few of the resources have lower temperatures (125-225°C). Compared to oil reservoir temperatures, geothermal reservoir temperatures are relatively higher. It could reach 350°C. Based on its reservoir temperatures, Hochstein (1990) divided geothermal systems into three systems as the following (ref. 1):

1. Low temperature geothermal system which have reservoir temperature ranges less than 125°C (low enthalpy).
2. Medium temperature geothermal systems which have reservoir temperature ranges between 125°C and 225°C (medium enthalpy).
3. High temperature geothermal systems which have reservoir temperature ranges higher than 225°C (high enthalpy).

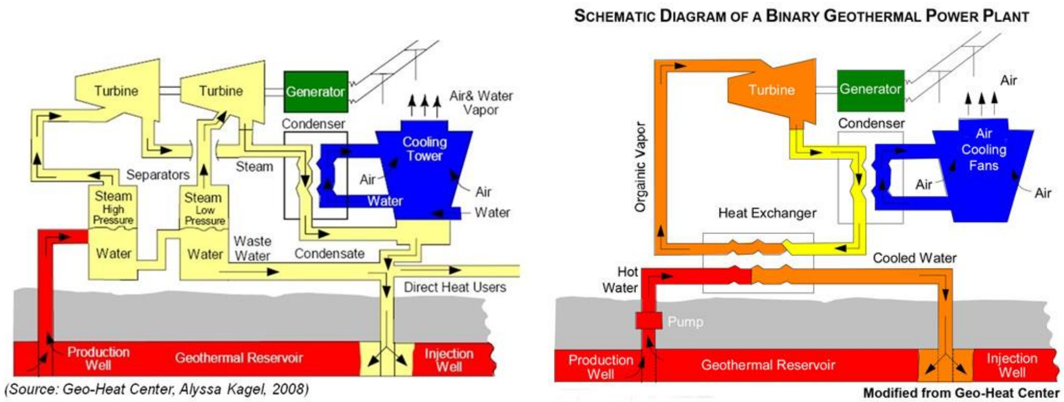
Geothermal to electrical power conversion systems typically in use in the world today may be divided into four energy conversion systems, which are:

- Direct steam plants; used at vapor-dominated reservoirs; dry saturated or slightly superheated steam with temperature range from 320°C down to some 200°C.
- Flashed steam plants; used at water-dominated reservoirs with temperatures greater than 182°C
  - Single flash plants; only high-pressure flash steam
  - Double flash plants; low and high-pressure flash steam
- Binary or twin-fluid system (based upon the Kalina or the Organic Rankin cycle); resource temperature range between 107°C to about 182°C.
- Hybrid; a combined system comprising two or more of the above basic types in series and/or in parallel.

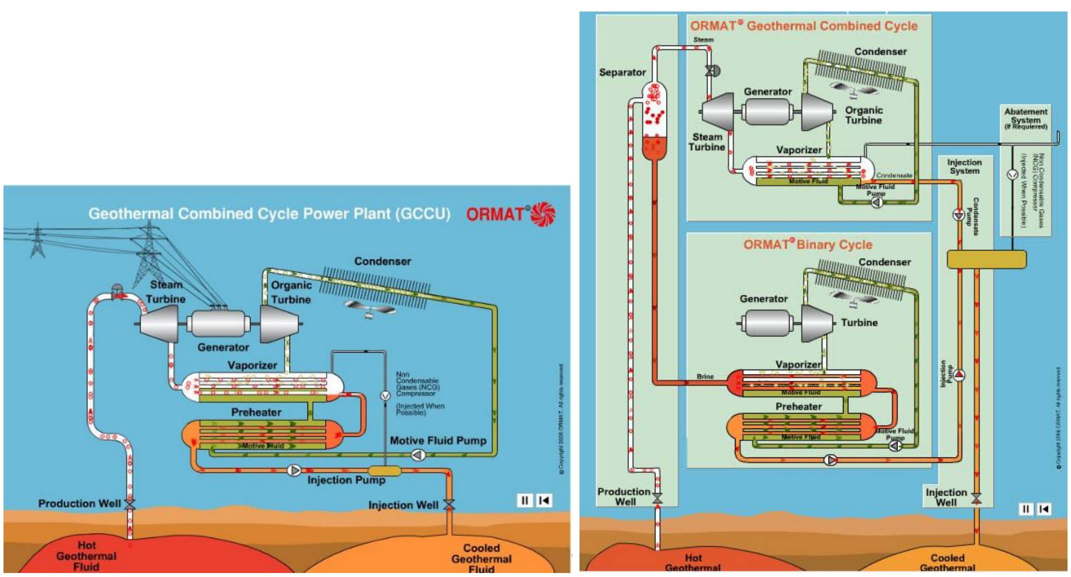
Condensing and back pressure type geothermal turbines are essentially low-pressure machines designed for operation at a range of inlet pressures ranging from about 20 bar down to 2 bar, and saturated steam. A condensing type system is the most common type of power conversion system in use today. They are generally manufactured in output module sizes of the following power ratings: 20 MW to 110 MW (the largest currently manufactured geothermal turbine unit is 117 MW). Binary type low/medium temperature units, such as the Kalina Cycle or Organic Rankin Cycle type, are typically manufactured in smaller modular sizes, i.e. ranging between 1 MW and 10 MW in size. Larger units specially tailored to a specific use are, however, available typically at a somewhat higher price.



Direct and single flashed steam plants (ref. 7)



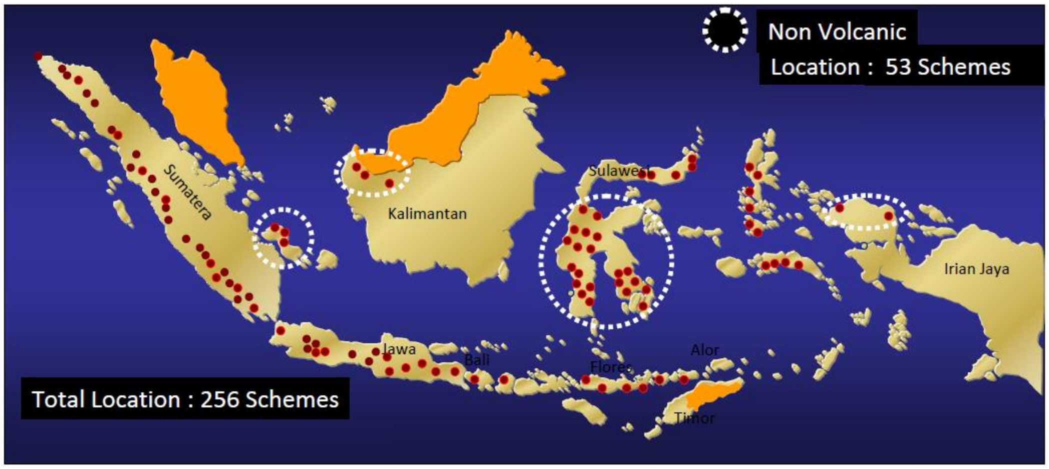
Double flashed and binary steam plants (ref. 7)



Hybrid/Combined Cycle plant (ref. 8)

The total capacity of geothermal power plants installed in 2015 in Indonesia was 1438 MW (ref. 2). In the same year, geothermal power plants have generated electricity of about 10 TWh. This equals to an average capacity factor of 80%. According to statistics of PT Indonesia Power 2015, the overall capacity factor of Kamojang, Salak and Darajat Geothermal Power Plants with total capacity of 345 MW could reach 96%. The current installed units have a capacity ranging from 2.5 to 110 MW per unit.

Indonesia has the largest geothermal resources potential in the world of about 29.5 GW, which comprises 12 GW of resources and 17.5 GW of reserves (ref. 2). The geothermal potential in Indonesia is mainly volcanic-type systems. This makes sense because Indonesia has more than 119 volcanoes along the ring of fire.



Distribution of geothermal in Indonesia

Geothermal resources and reserves potential (As of January 2016)

No	Islands	Resources (MW)		Reserves (MW)			Total (MW)
		Speculative	Hypothetic	Probable	Possible	Proven	
1	Sumatera	3,191	2,334	6,992	15	380	12,912
2	Jawa	1,560	1,739	4,023	658	1,815	9,795
3	Bali & Nusa Tenggara	295	431	1,179	0	15	1,920
4	Kalimantan	153	30	0	0	0	183
5	Sulawesi	1,221	318	1,441	150	78	3,208
6	Maluku	560	91	800	0	0	1,451
7	Papua	75	0	0	0	0	75
Total		7,055	4,943	14,435	823	2,288	29,544

Input
Heat from brine (saline water) from underground reservoirs.

Output
Electricity and Heat.

Typical capacities
2.5-110 MW per unit.

Ramping configurations
The general experience is that the geothermal energy should be used as base load to ensure an acceptable return on investment. For most geothermal power plants, flexibility is more of an economic issue than a technical one.

Advantages/disadvantages
Advantages:

- High degree of availability (>98% and 7500 operating hours/annum common).
- Small ecological footprints.
- Almost zero liquid pollution with re-injection of effluent liquid.
- Insignificant dependence on weather conditions.
- Comparatively low visual impact.
- Established technology for electricity production.
- Cheap running costs and "fuel" free.
- Renewable energy source and environmental friendly technology with low CO_2 emission.
- High operation stability and long lifetime.
- Potential for combination with heat storage.
- Geothermal is distinct from variable renewables, such as wind and solar, because it can provide consistent electricity throughout the day and year.

Disadvantages:

- No security for success before the first well is drilled and the reservoir has been tested (ref. 11).
- High initial costs.
- The best reservoirs not always located near cities.
- Need access to base-load electricity demand.
- The impact of the drilling on the nearby environment.
- Risk of mudslides if not handled properly.
- The pipelines to transport the geothermal fluids will have an impact on the surrounding area.

Environment
Steam from geothermal fields contains Non-Condensable Gas (NCG) such as Carbon Dioxide (CO_2), Hydrogen Sulfide (H_2S), Ammonia (NH_3), Nitrogen (N_2), Methane (CH_4) and Hydrogen (H_2). Among them, CO_2 is the largest element within the NCG's discharged. CO_2 constitutes up to 95 to 98% of the total gases, H_2S constitutes only 2 to 3%, and the other gasses are even less abundant.

H_2S is a colorless, flammable, and extremely hazardous gas. It causes a wide range of health effects, depending on concentration. Low concentrations of the gas irritate the eyes, nose, throat and respiratory system (e.g., burning/tearing of eyes, cough, shortness of breath). Safety threshold for hydrogen sulfide in humans can range from 0.0005 to 0.3 ppm.

CO_2 and H_2S are the dominant chemical compounds in geothermal steam, thus this catalog delivers data of CO_2 and H2S emission from geothermal power plants in Indonesia

NCG concentrations from each geothermal field are different. NCG emissions from Wayang Windu field would be 1.1%, and emissions from Kamojang field are 0.98%. Both of the fields produce dry steam. Ulubelu (two-phase steam) has NCG concentrations of 0.68%. The average NCG emissions from the three fields is 0.92% (ref. 3).

The table below shows the emissions concentrations of CO_2 and H_2S from three commissioned geothermal power plants in Indonesia. From the table, emissions of CO_2 range from 42 to 73 g/kWh with an average value of 62.90 g/kWh. For H_2S, the values range between 0.14 to 2.54 g/kWh with an average value of 1.45 g/kWh (ref. 3).

Power plant	Capacity (MWe)*	Emission (g/kWh)	
		CO_2	H_2S
Wayang Windu	227	73.48	2.54
Kamojang	235	72.57	0.14
Ulubelu	165	42.64	1.68
	Average:	62.90	1.45

*CO_2 and H_2S emission from geothermal power plant in Indonesia. *Total capacity in 2016*

Employment

During construction, the development of Lahendong Unit 5 and 6 and Ulubelu Unit 3 Geothermal Power Plants with total installed capacity of 95 MW have created around 2,750 jobs to the local work force. These power plants began to operate commercially in December 2016.

Research and development

Geothermal power plants are considered as a category 3 – i.e. commercial technologies, with potential of improvement.

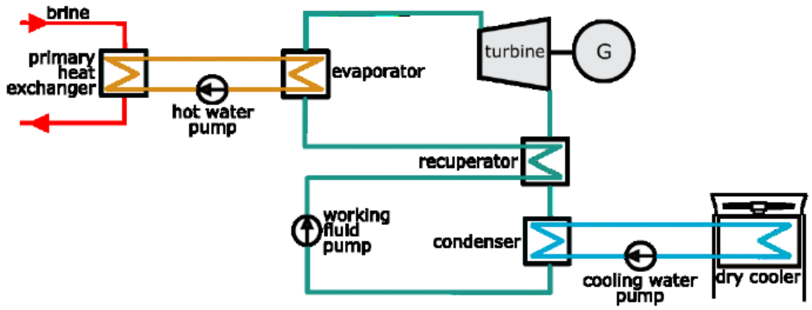
In order to successfully demonstrate binary power plant technologies at an Indonesian site and to stimulate the development of this technology, a German-Indonesian collaboration involving GFZ Potsdam (Germany), the Agency for the Assessment and Application of Technology in Indonesia (BPPT) and PT Pertamina Geothermal Energy (PGE) has been initiated. The basis for this collaboration was established within the German-Indonesian cooperation project "Sustainability concepts for exploitation of geothermal reservoirs in Indonesia" which started in 2009. Since then, several research activities have been carried out in the field of integrated geosciences and fluid-chemistry (ref. 6). In the field of plant technology, the technical concept for a demonstration binary power plant at the Lahendong, North Sulawesi site has been elaborated. The realization of the demonstration 550 kW binary power plant is carried out in a separate collaboration project which was officially granted in October 2013. Due to technical problems, the commissioning for demonstration of a binary cycle power plant has not yet be conducted. Commissioning will be conducted in mid-September 2017.

The binary power plant will use brine from well pad of LHD-5. The brine temperature is about 170°C corresponding to a separator pressure of 8.5 bar(g). The total mass flow will be about 110 t/h. The brine outlet temperature should be about 140 °C since it should be possible to inject the hot brine back into the reservoir in the western part of the geothermal system.

The power plant cycle will be a subcritical, single-stage Organic Rankine Cycle (ORC) with internal heat recovery using n-pentane as working fluid. For low maintenance and high reliability of the ORC, no rotating sealing are used in the conversion cycle. The feed pump will be a magnetic coupled type. Turbine-stage and generator will be mounted in one body and are directly connected by the shaft.

In the figure below, which shows the technical concept of the demonstration plant, it can be seen that the ORC-module is not directly driven by the geothermal fluid, since a water cycle between the brine cycle and ORC will be used. Material selection and design of the primary heat exchanger can hence be based on the brine composition whereas the evaporator design can be optimized with focus on the thermo-physical characteristic of the working fluid. For the heat removal from the ORC to the ambient by means of air-cooled equipment, an intermediate water cycle is also planned to minimize potential risks of malfunction in the conversion cycle. Using a water-cooled condenser also has the advantage to facilitate a factory test of the complete ORC-module prior to the final installation at the site. Both intermediate cycles will lead to a loss in power output due to the additional heat resistance and the additional power consumption by the intermediate cycle pumps and entail additional costs. However, the gain in plant reliability was considered to outweigh the power loss for this demonstration project. An intermediate cycle on the hot side might, however, also be advantageous for other sites.

The installed capacity will be about 550 kWe. The auxiliary power consumption is estimated to be lower than 20%.



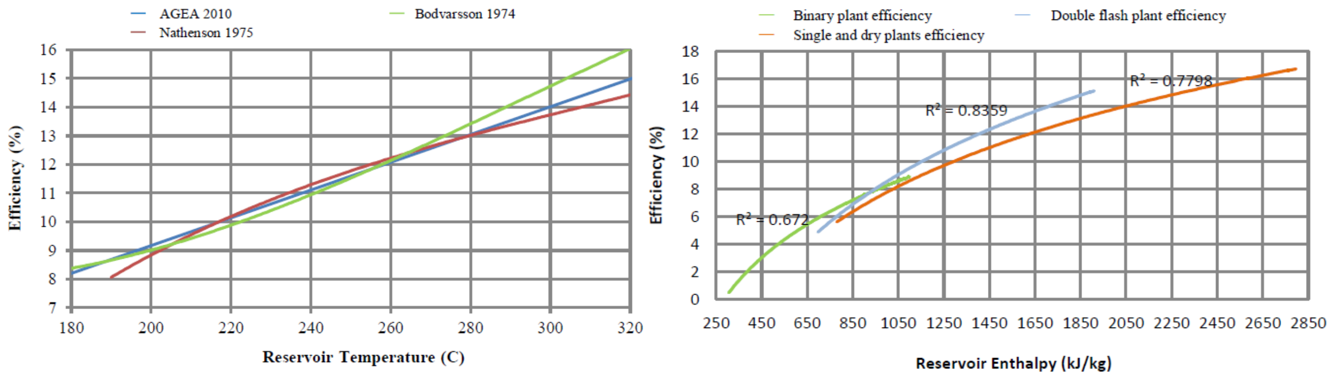
Technical concept of the demonstration power plant (ref. 4)

Examples of current projects

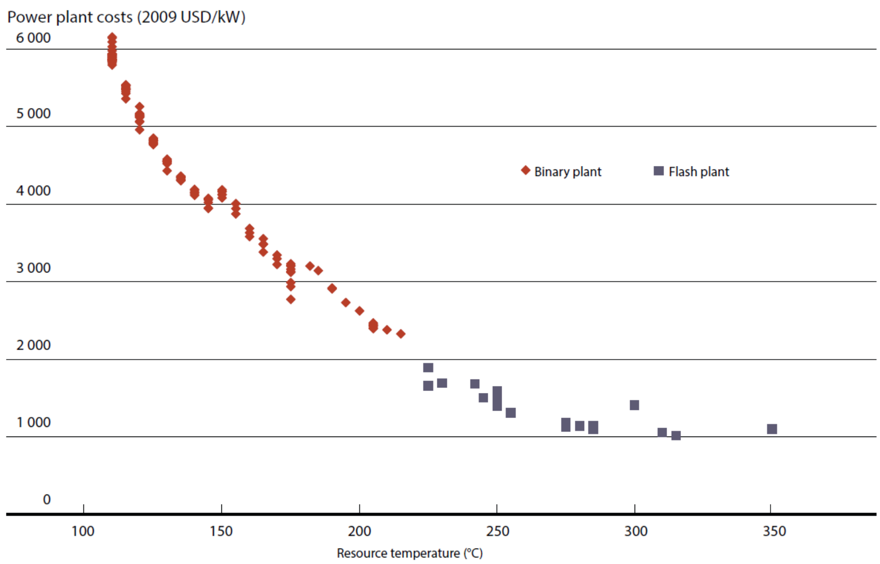
Sarulla Geothermal Project (3 x 110 MWe) is a core part of the Indonesian government's electricity development program (the Fast Track Program II) and a private-sector financed geothermal project to successfully conclude power purchase arrangements under that program. The first 110 MW unit of the Sarulla geothermal power plant has started commercial operation in 2016. The other two units are scheduled for operation in 2017 and 2018 respectively (ref. 9). The Project will be fueled by steam and brine from two production and injection facilities at Silangkitang and Namora-I-Langit reservoirs. The plants of the Project will apply Geothermal Combined Cycle Units which are more efficient than conventional flash type geothermal power plants. The plants will capture the steam and brine from the wells and produce energy throughout the day and is intended for base load operation. The condensate steam and the brine water will be re-injected underground via wells to maintain sustainable geothermal resources.

Additional remarks

The conversion efficiency of geothermal power developments is generally lower than that of conventional thermal power plants. The overall conversion efficiency is affected by many parameters including the power plant design (single or double flash, triple flash, dry steam, binary, or hybrid system), size, gas content, parasitic load, ambient conditions, and others. The figure below shows the conversion efficiencies for binary, single flash-dry steam, and double flash. The figure shows that double flash plants has higher conversion efficiency than single flash, but can have lower efficiency than binary plants for the low enthalpy range (750-850 kJ/kg). This has a direct impact on the specfic capital of the plant as shown in the following figure.



Geothermal plant efficiency as a function of temperature and enthalpy (ref. 5)



Indicative power plant only costs for geothermal projects by reservoir temperature (ref. 10). The power plant unit stands for around 40-50% of the total capital costs.

References

The following sources are used:

1. Hochstein, M.P., 1990. "Classification and assessment of geothermal resources" in: *Dickson MH and Fanelli M., Small geothermal resources*, UNITAEWNDP Centre for Small Energy Resources, Rome, Italy, 31-59.
2. MEMR, 2016. *Handbook of Energy & Economic Statistics of Indonesia 2016*, Ministry of Energy and Mineral Resources, Jakarta, Indonesia.
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4. Frick, et. al., 2015. "Geothermal Binary Power Plant for Lahendong, Indonesia: A German-Indonesian Collaboration Project", in *Proceedings World Geothermal Congress 2015* Melbourne, Australia.
5. Moon & Zarrouk, 2012. "Efficiency Of Geothermal Power Plants: A Worldwide Review", in *New Zealand Geothermal Workshop 2012 Proceedings*, Auckland, New Zealand.

6. Erabs, K. et al., 2015. "German-Indonesian Cooperation on Sustainable Geothermal Energy Development in Indonesia - Status and Perspectives". In *Proceedings World Geothermal Congress*. Melbourne, Australia.
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8. Ormat, Geothermal Power, www.ormat.com/geothermal-power, Accessed: 20th July 2017.
9. Sarulla Operation Ltd, Sarulla Geothermal Project, www.sarullaoperations.com/overview.html, Accessed: 20th July 2017.
10. IRENA, 2015, Renewable Power Generation Costs in 2014.
11. Geothermal Energy Association, 2006, "A Handbook on the Externalities, Employment, and Economics of Geothermal Energy".

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Geothermal power plant - small system (binary or condensing)								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	10	10	10	0.3	20	0.3	20		1,8
Generating capacity for total power plant (MWe)	20	20	20	5	30	5	30		1
Electricity efficiency, net (%), name plate	10	11	12	6	12	8	14	A	5
Electricity efficiency, net (%), annual average	10	11	12	6	12	8	14	A	5
Forced outage (%)	10	10	10	5	30	5	30		1
Planned outage (weeks per year)	4	4	4	2	6	2	6		1
Technical lifetime (years)	30	30	30	20	50	20	50		1
Construction time (years)	2.0	2.0	2.0	1,5	3	1,5	3		1
Space requirement (1000 m^2/MWe)	30	31	32	20	40	20	40		1
Additional data for non thermal plants									
Capacity factor (%), theoretical	90	90	90	70	100	70	100		1
Capacity factor (%), incl. outages	80	80	80	70	100	70	100		1
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-	B	6
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-	B	6
NO_X (g per GJ fuel)	-	-	-	-	-	-	-	B	6
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-	B	6
N_2O (g per GJ fuel)	-	-	-	-	-	-	-	B	6
Financial data									
Nominal investment (M$/MWe)	4.5	4.2	3.8	3.4	5.7	2.9	4.8	C,D,E	1,2,4,8
- of which equipment	60%	60%	60%	40%	70%	40%	70%		3
- of which installation	40%	40%	40%	30%	50%	30%	50%		3
Fixed O&M ($/MWe/year)	20,000	18,500	16,900	15,000	25,000	12,700	21,100	C,D	1,4
Variable O&M ($/MWh)	0.37	0.34	0.31	0.28	0.46	0.23	0.39	C,D	1,4
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Exploration costs (M$/MWe)	0.15	0.15	0.15	0.10	0.20	0.10	0.20		7
Confirmation costs (M$/MWe)	0.15	0.15	0.15	0.10	0.20	0.10	0.20		7

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Budisulistyo & Krumdieck , 2014, "Thermodynamic and economic analysis for the pre- feasibility study of a binary geothermal power plant"

3 IRENA, 2015, Renewable Power Generation Costs in 2014.

4 Learning curve approach for the development of financial parameters.

5 Moon & Zarrouk, 2012, "Efficiency Of Geothermal Power Plants: A Worldwide Review".

6 Yuniarto, et. al., 2015. "Geothermal Power Plant Emissions in Indonesia".

7 Geothermal Energy Association, 2006, "A Handbook on the Externalities, Employment, and Economics of Geothermal Energy".

8 Climate Policy Initiative, 2015, Using Private Finance to Accelerate Geothermal Deployment: Sarulla Geothermal Power Plant, Indonesia.

Notes:

A The efficiency is the thermal efficiency - meaning the utilization of heat from the ground. Since the geothermal heat is renewable and considered free, then an increase in effciency will give a lower investment cost per MW. These smaller units are assumed to be binary units at medium source temperatures.

B Geothermal do emit H_2S. From Minister of Environment Regulation 21/2008 this shall be below 35 mg/Nm^3.

C Uncertainty (Upper/Lower) is estimated as +/- 25%.

D Investment cost are including Exploration and Confirmation costs (see under Technology specific data).

E Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

Technology	Geothermal power plant - large system (flash or dry)								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	55	55	55	30	500	30	500		1
Generating capacity for total power plant (MWe)	110	110	110	30	500	30	500		1
Electricity efficiency, net (%), name plate	16	17	18	8	18	10	20	A	5
Electricity efficiency, net (%), annual average	15	16	17	8	18	10	20	A	5
Forced outage (%)	10	10	10	5	30	5	30		1
Planned outage (weeks per year)	4	4	4	2	6	2	6		1
Technical lifetime (years)	30	30	30	20	50	20	50		1
Construction time (years)	2.0	2.0	2.0	1,5	3	1,5	3		1
Space requirement (1000 m^2/MWe)	30	30	30	20	40	20	40		1
Additional data for non thermal plants									
Capacity factor (%), theoretical	90	90	90	70	100	70	100		1
Capacity factor (%), incl. outages	80	80	80	70	100	70	100		1
Ramping configurations									
Ramping (% per minute)	3	10	20						8
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-	C	6
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-	C	6
NO_X (g per GJ fuel)	-	-	-	-	-	-	-	C	6
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-	C	6
N_2O (g per GJ fuel)	-	-	-	-	-	-	-	C	6
Financial data									
Nominal investment (M$/MWe)	3.5	3.2	2.9	2.6	4.4	2.2	3.7	B,D,E	1,2,3,4
- of which equipment	60%	60%	60%	40%	70%	40%	70%		3
- of which installation	40%	40%	40%	30%	50%	30%	50%		3
Fixed O&M ($/MWe/year)	18,000	16,700	15,200	13,500	22,500	11,400	19,000	B,D	1,4
Variable O&M ($/MWh)	0.25	0.23	0.21	0.19	0.31	0.16	0.26	B,D	1,4
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Exploration costs (M$/MWe)	0.15	0.15	0.15	0.10	0.20	0.10	0.20		7
Confirmation costs (M$/MWe)	0.15	0.15	0.15	0.10	0.20	0.10	0.20		7

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 IEA, World Energy Outlook, 2015.

3 IRENA, 2015, Renewable Power Generation Costs in 2014.

4 Learning curve approach for the development of financial parameters.

5 Moon & Zarrouk, 2012, "Efficiency Of Geothermal Power Plants: A Worldwide Review".

6 Yuniarto, et. al., 2015. "Geothermal Power Plant Emissions in Indonesia".

7 Geothermal Energy Association, 2006, "A Handbook on the Externalities, Employment, and Economics of Geothermal Energy".

8 Geothermal Energy Association, 2015, "Geothermal Energy Association Issue Brief: Firm and Flexible Power Services Available from Geothermal Facilities"

Notes:

A The efficiency is the thermal efficiency - meaning the utilization of heat from the ground. Since the geothermal heat is renewable and considered free, then an increase in effciency will give a lower investment cost per MW. These large units are assumed to be flach units at high source temperatures.

B Uncertainty (Upper/Lower) is estimated as +/- 25%, which is an estimate build upon cases from IRENA (ref. 3)

C Geothermal do emit H_2S. From Minister of Environment Regulation 21/2008 this shall be below 35 mg/Nm^3.

D The learning rate is assumed to impact the geothermal specific equipment and installation. The power plant units (i.e. the turbine and pump) is assumed to have very litle development. From Ref. 3 it is assumed that half of the investment cost are on the geothermal specific equipment.

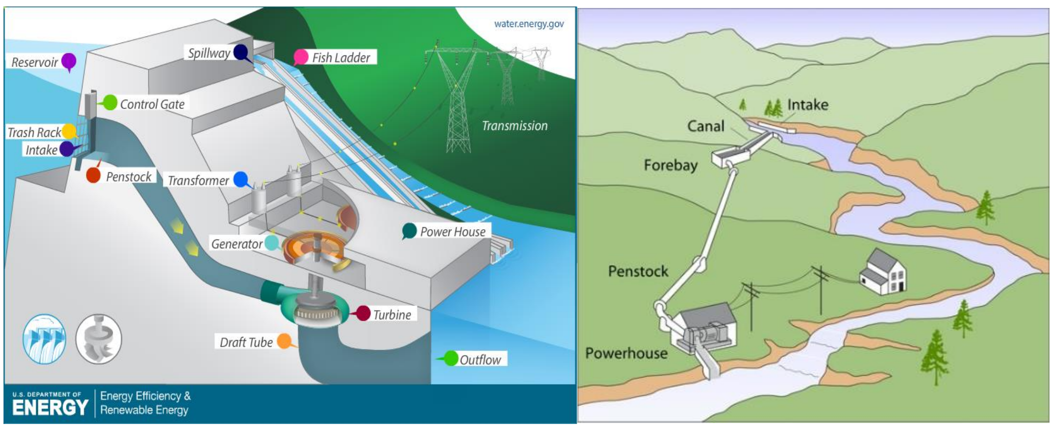
E Investment cost are including Exploration and Confirmation costs (see under Technology specific data).

2. HYDRO POWER PLANT

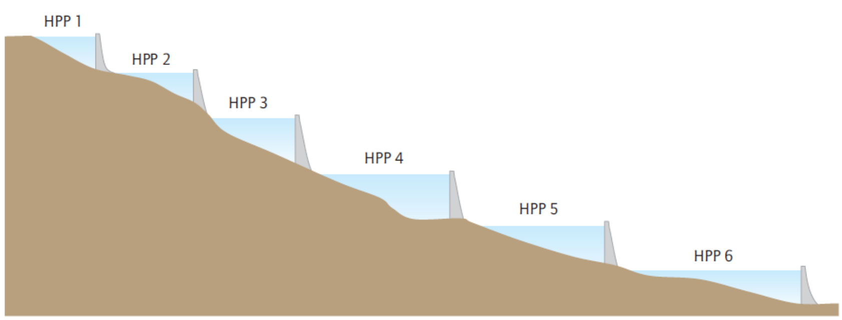
Brief technology description

There are three types of hydro power facilities:

- Run-of-river
  A facility that channels flowing water from a river through a canal or penstock to spin a turbine. Typically, a run-of-river project will have little or no storage facility.
- Storage/reservoir
  Using a dam to store water in a reservoir. Electricity is produced by releasing water from the reservoir through a turbine, which activates a generator.
- Pumped-storage
  Providing peak-load supply, harnessing water which is cycled between a lower and upper reservoir by pumps which use surplus energy from the system at times of low demand. (This will be explained more detailed in chapter 12)



Reservoir and run-of-river hydropower plants (ref. 15)



Cascading Systems (ref. 1)

Run-of-river and reservoir hydropower plants can be combined in cascading river systems and pumped storage plants can utilize the water storage of one or several reservoir hydropower plants. In Cascading systems, the energy output of a run-of-river hydropower plant could be regulated by an upstream reservoir hydropower plant, as in cascading hydropower schemes. A large reservoir in the upper catchment generally regulates outflows for several run-of-rivers or smaller reservoir plants downstream. This likely increases the yearly energy potential of downstream sites, and enhances the value of the upper reservoir's storage function.

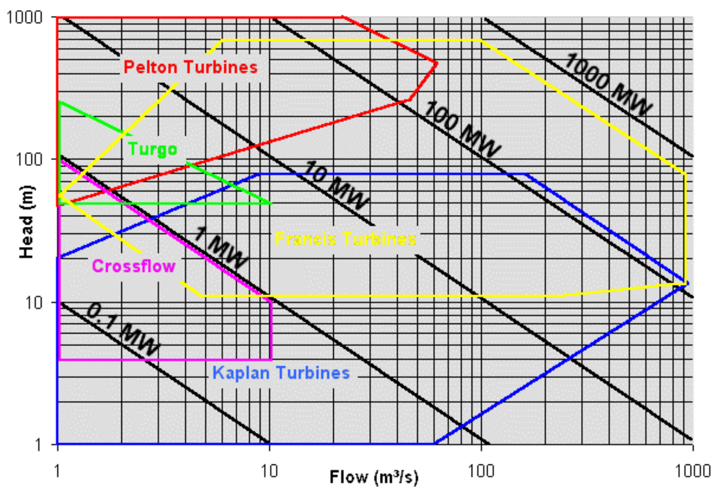
In Indonesia, big cascading systems can be found at Citarum River and Brantas River basins in West and East Jawa respectively. There are three hydropower plants installed at Citarum River. They are, from upstream to downstream, Saguling (700 MW), Cirata (1008 MW) and Jatiluhur (150 MW) hydropower plants. At Brantas River, there are twelve hydropower plants in operation with total capacity of 281 MW.

Hydropower systems can range from tens of Watts to hundreds of Megawatts. A classification based on the size of hydropower plants for Indonesia is presented in table below. However, there is no internationally recognized standard definition for hydropower sizes, so definitions can vary from one country to another.

Classification of hydro-power size (ref. 2)

Type	Capacity
Large hydro power	> 100 MW
Medium hydro power	10 – 100 MW
Mini hydro power	1 MW – 10 MW
Micro hydro power	5 - 1000 kW
Pico hydro power	< 5 kW

Large hydropower plants often have outputs of hundreds or even thousands of megawatts and use the energy in falling water from the reservoir to produce electricity using a variety of available turbine types (e.g. Pelton, Francis, Kaplan) depending on the characteristics of the river and installation capacity. Small, mini, micro and pico hydropower plants are run-of-river schemes. These types of hydropower use Cross-flow, Pelton, or Kaplan turbines. The selection of turbine type depends on the head and flow rate of the river.



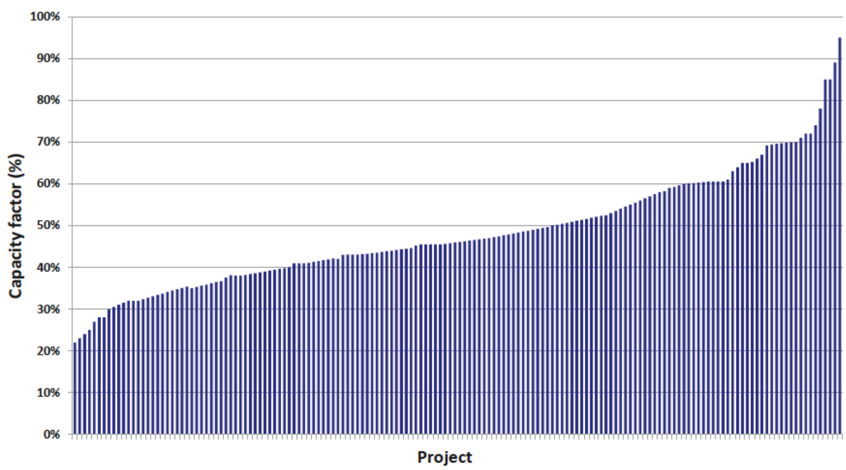
Hydropower turbine application chart (ref. 3)

For high heads and small flows, Pelton turbines are used, in which water passes through nozzles and strikes spoon-shaped buckets arranged on the periphery of a wheel. A less efficient variant is the cross-flow turbine. These are action turbines, working only from the kinetic energy of the flow. Francis turbines are the most common type, as they accommodate a wide range of heads (20 m to 700 m), small to very large flows, a broad rate capacity and excellent hydraulic efficiency.

For low heads and large flows, Kaplan turbines, a propeller-type water turbine with adjustable blades, dominate. Kaplan and Francis turbines, like other propeller-type turbines, capture the kinetic energy and the pressure difference of the fluid between entrance and exit of the turbine.

In 2015 the total capacity of hydropower plants installed in Indonesia was 5079 MW. At the same time, total electricity produced from hydropower plants was 13,741 GWh (ref. 4). Then, the capacity factor of hydropower was only 31%. The reason why the average capacity factor of hydropower plants is quite low in Indonesia is that some of the plants are operated as peak load, especially the plants in Java island such as Cirata and Saguling hydropower plants. Among other type of power plants, hydropower is the one that has high capability to ramp its capacity up or down to meet fluctuating demand within quite short time.

The capacity factor achieved by hydropower projects needs to be looked at somewhat differently than for other renewable projects. It depends on the availability of water and also the purpose of the plants whether for meeting peak and/or base demand. Data for 142 Clean Development Mechanism (CDM) projects around the world yield capacity factors of between 23% and 95%. The average capacity factor was 50% for these projects.



Capacity factors for 142 hydropower projects around the world (ref. 5)

Indonesia has an abundance of hydropower resource potential. It is estimated that the untapped hydropower potential is about 94.5 GW (ref. 4). According to the same source, about 19,4 GW of the potential is classified as micro hydropower potential.

Hydro resources potential (from EBTKE)

No	Island	Hydro (GW)	Micro Hydro (GW)
1	Sumatera	15.60	5.73
2	Jawa	4.20	2.91
3	Kalimantan	21.60	8.10
4	Sulawesi	10.20	1.67
5	Bali and Nusa Tenggara	0.62	0.14
6	Maluku	0.43	0.21
7	Papua	22.35	0.62
Total		75.00	19.37

Input
The falling water from either reservoir or run-of-river having certain head and flow rate.

Output
Electricity.

Typical capacities
Hydropower systems can range from tens of Watts to hundreds of Megawatts. Currently up to 900 MW per unit (ref. 16). The largest unit capacity of hydropower plant turbine which has ever been installed in Indonesia is 175 MW at PLTA Saguling, West Java.

Ramping configurations
Hydropower helps to maintain the power frequency by continuous modulation of active power, and to meet moment-to-moment fluctuations in power requirements. It offers rapid ramp rates and usually very large ramp ranges, making it very efficient to follow steep load variations or intermittent power supply of renewable energy such as wind and solar power plants.

Advantages/disadvantages
Advantages:
- Hydropower is fueled by water, so it's a clean fuel source. Hydropower doesn't pollute the air.
- Hydropower is a domestic source of energy, produced locally in Indonesia.
- Hydropower relies on the water cycle, which is driven by the sun, thus it's a renewable power source.
- Hydropower is generally available as needed; engineers can control the flow of water through the turbines to produce electricity on demand.
- Hydropower facilities have a very long service life, which can be extended indefinitely, and further improved. Some operating facilities in certain countries are 100 years and older. This makes for long-lasting, affordable electricity.
- Hydropower plants provide benefits in addition to clean electricity. Impoundment hydropower creates reservoirs that offer a variety of recreational opportunities, notably fishing, swimming, and boating. Other benefits may include water supply, irrigation and flood control.

Disadvantages:
- Fish populations can be impacted if fish cannot migrate upstream past impoundment dams to spawning grounds or if they cannot migrate downstream to the ocean.
- Hydropower can impact water quality and flow. Hydropower plants can cause low dissolved oxygen levels in the water, a problem that is harmful to riverbank habitats.
- Hydropower plants can be impacted by drought. When water is not available, the hydropower plants can't produce electricity.
- Hydropower plants can be impacted by sedimentation. Sedimentation affects the safety of dams and reduces energy production, storage, discharge capacity and flood attenuation capabilities. It increases loads on the dam and gates, damages mechanical equipment and creates a wide range of environmental impacts.
- New hydropower facilities impact the local environment and may compete with other uses for the land. Those alternative uses may be more highly valued than electricity generation. Humans, flora, and fauna may lose their natural habitat. Local cultures and historical sites may be impinged upon.

- If the catchment area is not managed properly the water source can be significantly lower than expected.

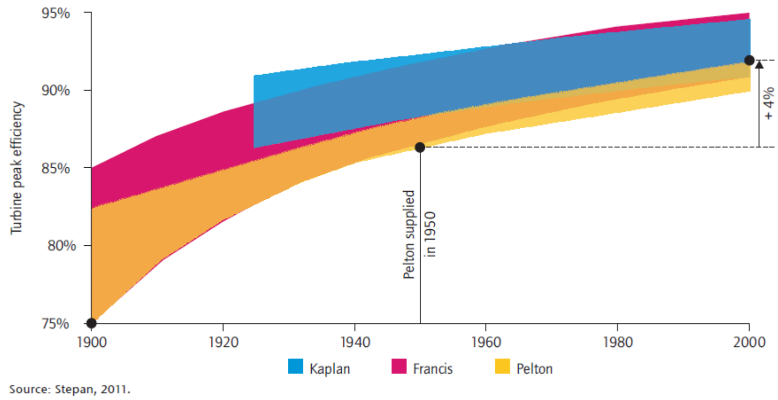
Environment
Environmental issues identified in the development of hydropower include:

- Safety issues;
  Hydropower is very safe today. Losses of life caused by dam failure have been very rare in the last 30 years. The population at risk has been significantly reduced through the routing and mitigation of extreme flood events.
- Water use and water quality impacts;
  The impact of hydropower plants on water quality is very site specific and depends on the type of plant, how it is operated and the water quality before it reaches the plant. Dissolved oxygen (DO) levels are an important aspect of reservoir water quality. Large, deep reservoirs may have reduced DO levels in bottom waters, where watersheds yield moderate to heavy amounts of organic sediments.
- Impacts on migratory species and biodiversity;
  Older dams with hydropower facilities were often developed without due consideration for migrating fish. Many of these older plants have been refurbished to allow both upstream and downstream migration capability.
- Implementing hydropower projects in areas with low or no anthropogenic activity;
  In areas with low or no anthropogenic activity the primary goal is to minimize the impacts on the environment. One approach is to keep the impact restricted to the plant site, with minimum interference over forest domains at dams and reservoir areas, e.g. by avoiding the development of villages or cities after the construction periods.
- Reservoir sedimentation and debris;
  This may change the overall geomorphology of the river and affect the reservoir, the dam/power plant and the downstream environment. Reservoir storage capacity can be reduced, depending on the volume of sediment carried by the river.
- Lifecycle greenhouse gas emissions.
  Life-cycle CO_2 emissions from hydropower originate from construction, operation and maintenance, and dismantling. Possible emissions from land-use related net changes in carbon stocks and land management impacts are very small.

Employment
Generally, a new large hydro power plant (110 MW) project will provide around 2,000 – 3,000 local jobs during construction phase. The kind of jobs expected are technicians, welders, joineries, carpenters, porters, project accountants, electrical and mechanical engineers, cooks, cleaners, masons, security guards and many others. Of those, about 150 - 200 of them will continue to work at the facility. (ref. 19)

Research and development
Hydropower is a very mature and well-known technology (category 4). While hydropower is the most efficient power generation technology, with high energy payback ratio and conversion efficiency, there are still many areas where small but important improvements in technological development are needed.

- Improvements in turbines
  The hydraulic efficiency of hydropower turbines has shown a gradual increase over the years: modern equipment reaches 90% to 95%. This is the case for both new turbines and the replacement of existing turbines (subject to physical limitations).

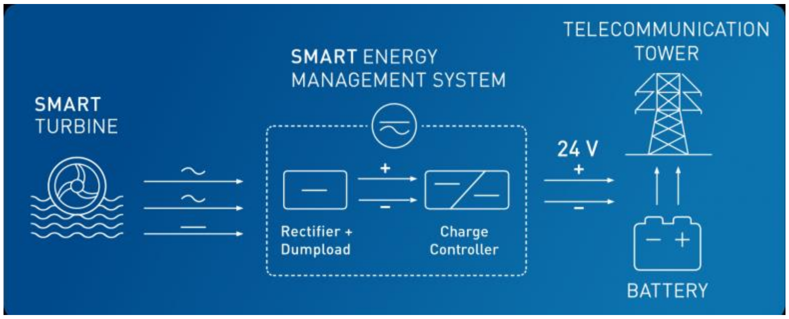


Improvement of hydraulic performance over time (ref. 8)

Some improvements aim directly at reducing the environmental impacts of hydropower by developing

- Fish-friendly turbines
- Aerating turbines
- Oil-free turbines

- Hydrokinetic turbines
  Kinetic flow turbines for use in canals, pipes and rivers. In-stream flow turbines, sometimes referred to as hydrokinetic turbines, rely primarily on the conversion of energy from free-flowing water, rather than from hydraulic head created by dams or control structures. Most of these underwater devices have horizontal axis turbines, with fixed or variable pitch blades. In Indonesia, a collaboration among PT Bima Green Energy, PT Telkomsel Indonesia and Smart Hydro Power GmBH, a German company, has installed two units of 5 kW pico hydropower with hydrokinetic turbine in Tabang, East Kalimantan to power a telecommunication tower located at a remote area which is not connected to the grid.



Pico hydropower with hydrokinetic turbine for remote telecommunication towers (ref. 17)

- Bulb (Tubular) turbines;
  Nowadays, very low heads can be used for power generation in a way that is economically feasible. Bulb turbines are efficient solutions for low head up to 30 m. The term "Bulb" describes the shape of the upstream watertight casing which contains a generator located on a horizontal axis. The generator is driven by a variable-pitch propeller (or Kaplan turbine) located on the downstream end of the bulb.
- Improvements in civil works;
  The cost of civil works associated with new hydropower project construction can be up to 70% of the total project cost, so improved methods, technologies and materials for planning, design and construction have

considerable potential (ref. 14). A roller-compacted concrete (RCC) dam is built using much drier concrete than traditional concrete gravity dams, allowing speedier and lower cost construction.
- Upgrade or redevelop old plants to increase efficiency and environmental performance.
- Add hydropower plant units to existing dams or water flows.

Examples of current projects

Admittedly, technology in the hydropower field doesn't move nearly as quickly as other areas, for example computers or mobile phones. Hydropower is a mature technology. The world's largest operating hydropower plant is the Three Gorges plant in China with a capacity of 22.5 GW. The plant generated 98.1 TWh in 2012 (ref. 9). The second largest hydropower plant is Itaipu in Brazil/Paraguay, with a 14 GW capacity and a generation of 98.2 TWh in 2012 (ref. 18). Both hydropower plants use Francis type turbines with unit capacity reaching up to 767 MW. Meanwhile the largest hydropower plant which has ever been built in Indonesia is Cirata hydropower plant. It has two units of generation with total capacity of 1008 MW. The last unit was commercially operational in 1997. Francis type turbines are also used in the Cirata hydropower plant. Brazil operates the 3,150 MW Santo Antonio hydropower plant on the Madeira River in the Amazon rainforest near Bolivia. The plant design calls for use of 88 bulb type turbines. Some of them has unit capacity of 75 MW. This is the most powerful bulb in operation at present (ref. 16).

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2. PLN, System Planning Division, 2017.
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Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* it related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Hydro power plant - Mini/micro system								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	5	5	5	1	10	1	10		1,8
Generating capacity for total power plant (MWe)	5	5	5	1	10	1	10		1,8
Electricity efficiency, net (%), name plate	80	80	80	70	90	70	90	A	7
Electricity efficiency, net (%), annual average	80	80	80	70	90	70	90	A	7
Forced outage (%)	4	4	4	2	10	2	10		
Planned outage (weeks per year)	6	6	6	3	10	3	10		
Technical lifetime (years)	50	50	50	40	90	40	90	B	
Construction time (years)	2	2	2	1.5	3	1.5	3		
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical	80	80	80	50	95	50	95		2,10
Capacity factor (%), incl. outages	76	76	76	50	95	50	95		2,10
Ramping configurations									
Ramping (% per minute)	-	-	-	-	-	-	-	E	
Minimum load (% of full load)	-	-	-	-	-	-	-	E	
Warm start-up time (hours)	-	-	-	-	-	-	-	E	
Cold start-up time (hours)	-	-	-	-	-	-	-	E	
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	2.6	2.6	2.6	1.2	4.0	1.2	4.0	D,F	1,5,9
- of which equipment	30%	30%	30%	20%	50%	20%	50%		9
- of which installation	70%	70%	70%	50%	80%	50%	80%		9
Fixed O&M ($/MWe/year)	53,000	50,400	47,200	39,800	66,300	35,400	59,000	C	1,5,9
Variable O&M ($/MWh)	0.50	0.48	0.45	0.38	0.63	0.33	0.56	C	1,5
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Branche, 2011, “Hydropower: the strongest performer in the CDM process, reflecting high quality of hydro in comparison to other renewable energy sources”.

3 Eurelectric, 2015, "Hydropower - Supporting a power system in transition".

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9 ASEAN, 2016, "Levelised cost of electricity of selected renewable technologies in the ASEAN member states".

10 MEMR, 2016, "Handbook of Energy & Economic Statistics of Indonesia 2016", Ministry of Energy and Mineral Resources, Jakarta, Indonesia.

Notes:

A This is the efficiency of the utilization of the waters potential energy. This can not be compared with a thermal power plant that have to pay for its fuel.

B Hydro power plants can have a very long lifetime is operated and mainted properbly. Hover Dam in USA is almost 100 years old.

C Uncertainty (Upper/Lower) is estimated as +/- 25%.

D Numbers are very site sensitive and the uncertainty can be even more extreme than listed. There will be an improvement by learning curve development, but this improvement will equalized because the best locations will be utilized first. The investment largely depends on civil work.

E It is assumed that micro and mini hydro do not have a reservior (run-of-river) and therefor is not capable of regulation. The possibility of a turbine bypass could give the possibility of down regulation.

F Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

Technology	Hydro power plant - Medium system								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	50	50	50	10	100	10	100		2
Generating capacity for total power plant (MWe)	50	50	50	20	100	20	100		2
Electricity efficiency, net (%), name plate	95	95	95	85	97	85	97	A	1
Electricity efficiency, net (%), annual average	95	95	95	85	97	85	97	A	1
Forced outage (%)	4	4	4	2	10	2	10		1
Planned outage (weeks per year)	6	6	6	3	10	3	10		1
Technical lifetime (years)	50	50	50	40	90	40	90		1
Construction time (years)	3	3	3	2	6	2	6		1
Space requirement (1000 m^2/MWe)	14	14	14	11	18	11	18	B	
Additional data for non thermal plants									
Capacity factor (%), theoretical	80	80	80	50	95	50	95		8,9
Capacity factor (%), incl. outages	76	76	76	50	95	50	95		8,9
Ramping configurations									
Ramping (% per minute)	50	50	50	30	100	30	100		3
Minimum load (% of full load)	0	0	0	0	0	0	0		3
Warm start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		3
Cold start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		3
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	2.2	2.2	2.2	1.4	5.2	1.4	5.2	C,D	4,5,6,7
- of which equipment	30%	30%	30%	20%	50%	20%	50%		7
- of which installation	70%	70%	70%	50%	80%	50%	80%		7
Fixed O&M ($/MWe/year)	41,900	39,800	37,300	22,000	41,900	22,000	41,900		4,5,7
Variable O&M ($/MWh)	0.50	0.48	0.45	0.38	0.63	0.33	0.56	B	1
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Size of reservoir (MWh)									

References:

1 Stepan, 2011, Workshop on Rehabilitation of Hydropower, “The 3-Phase Approach”.

2 Prayogo, 2003, "Teknologi Mikrohidro dalam Pemanfaatan Sumber Daya Air untuk Menunjang Pembangunan Pedesaan. Semiloka Produk-produk Penelitian Departement Kimpraswill Makassar".

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C Numbers are very site sensitive. There will be an improvement by learning curve development, but this improvement will equalized because the best locations will be utilized first. The investment largely depends on civil work.

D Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

Technology	Hydro power plant - large system								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	150	150	150	100	2000	100	2000		1,8,10
Generating capacity for total power plant (MWe)	150	150	150	100	2000	100	2000		1,8,10
Electricity efficiency, net (%), name plate	95	95	95	85	97	85	97	A	7
Electricity efficiency, net (%), annual average	95	95	95	85	97	85	97	A	7
Forced outage (%)	4	4	4	2	10	2	10		1
Planned outage (weeks per year)	6	6	6	3	10	3	10		1
Technical lifetime (years)	50	50	50	40	90	40	90	B	1
Construction time (years)	4	4	4	2	6	2	6		1
Space requirement (1000 m^2/MWe)	62	62	62	47	78	47	78	C	1
Additional data for non thermal plants									
Capacity factor (%), theoretical	40	40	40	20	95	20	95		2,12
Capacity factor (%), incl. outages	36	36	36	20	95	20	95		2,12
Ramping configurations									
Ramping (% per minute)	50	50	50	30	100	30	100		3
Minimum load (% of full load)	0	0	0	0	0	0	0		3
Warm start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		3
Cold start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		3
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	2.0	2.0	2.0	0.6	8.0	0.6	8.0	D,E	1,4,5,6,9
- of which equipment	30%	30%	30%	20%	50%	20%	50%		11
- of which installation	70%	70%	70%	50%	80%	50%	80%		11
Fixed O&M ($/MWe/year)	37,700	35,800	33,600	28,300	47,100	25,200	42,000	C	1,4,5,6
Variable O&M ($/MWh)	0.65	0.62	0.58	0.49	0.81	0.43	0.72	C	1,5
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Size of reservoir (MWh)									

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Branche, 2011, "Hydropower: the strongest performer in the CDM process, reflecting high quality of hydro in comparison to other renewable energy sources".

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D Numbers are very site sensitive. There will be an improvement by learning curve development, but this improvement will equalized because the best locations will be utilized first. The investment largely depends on civil work.

E Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

3. SOLAR PHOTOVOLTAICS

Brief technology description
A solar cell is a semiconductor component that generates electricity when exposed to light. For practical reasons several solar cells are typically interconnected and laminated to (or deposited on) a glass pane in order to obtain a mechanical ridged and weathering protected solar module. The photovoltaic (PV) modules are typically 1-2 m^2 in size and have a power density in the range 100-210 Watt-peak pr. m^2 (Wp/m^2). They are sold with a product guarantee of typically two-five years, a power warranty of minimum 25 years and an expected lifetime of more than 30 years.

PV modules are characterised according to the type of absorber material used:

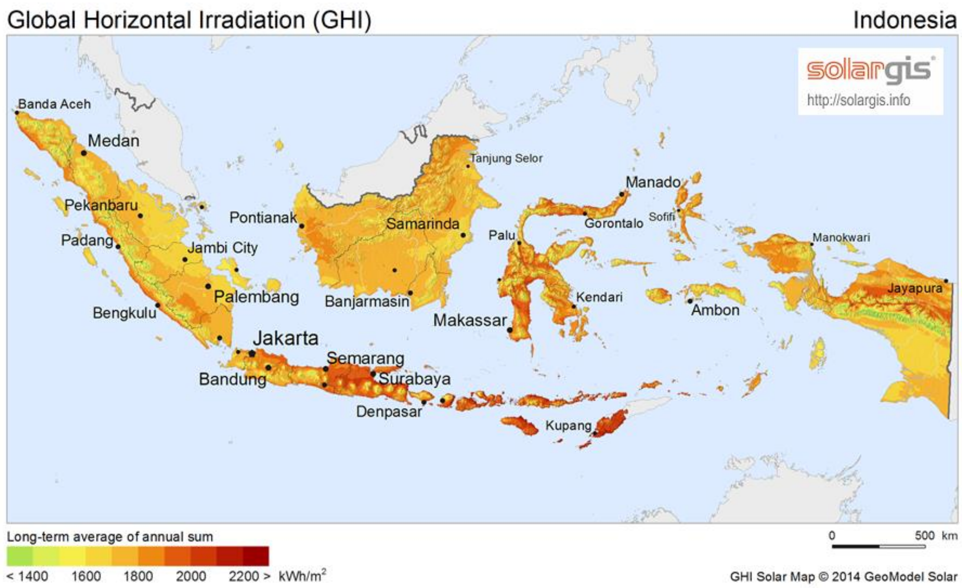
- Crystalline silicon (c-Si); the most widely used substrate material is made from purified solargrade silicon and comes in the form of mono- or multi-crystalline silicon wafers. Currently more than 90 pct. of all PV modules are wafer-based divided between multi- and mono-crystalline. This technology platform is expected to dominate the world market for decades due to significant cost and performance advantages (ref. 1). Future improvements include development from monofacial to bifacial modules, which convert light captured on both the front and the back of the cell into power (ref. 6).
- Thin film solar cells; where the absorber can be an amorphous/microcrystalline layer of silicon (a-Si/μc-Si), Cadmium telluride (CdTe) or Copper Indium Gallium (di)Selenide (CIGS). These semiconductor materials are deposited on the top cover glass of the solar module in a micrometre thin layer. Tandem junction and triple junction thin film modules are commercially available. In these modules several layers are deposited on top of each other in order to increase the efficiency (ref. 1).
- Monolithic III-V solar cells; that are made from compounds of group III and group V elements (Ga, As, In and P), often deposited on a Ge substrate. These materials can be used to manufacture highly efficient multi-junction solar cells that are mainly used for space applications or in Concentrated Photovoltaic (CPV) systems (ref. 1).
- Perovskite material PV cells; Perovskite solar cells are in principle a Dye Sensitized solar cell with an organo-metal salt applied as the absorber material. Perovskites can also be used as an absorber in modified (hybrid) organic/polymer solar cells. The potential to apply perovskite solar cells in a multi-stacked cell on e.g. a traditional c-Si device provides interesting opportunities (ref. 1).

In addition to PV modules, a grid connected PV system also includes Balance of System (BOS) consisting of a mounting system, dc-to-ac inverter(s), cables, combiner boxes, optimizers, monitoring/surveillance equipment and for larger PV power plants also transformer(-s). The PV module itself accounts for approximately 50% of the total system costs, inverters around 5-10%.

Input
Solar radiation. The irradiation, which the module receives, depends on the solar energy resource potential at the location, including shade and the orientation of the module (both tilting from horizontal plane and deviation from facing south).

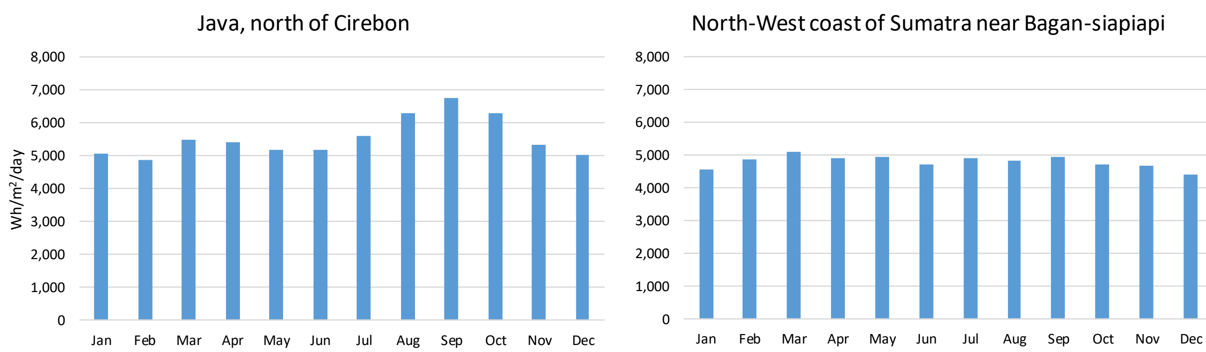
The average annual solar energy received on a horizontal surface (Global Horizontal Irradiance, GHI) in Indonesia varies between approx. 1500 kWh and 2200 kWh per m^2. In general, Java, Sulawesi, Bali and East and

West Nusa Tenggara demonstrate the best solar locations whereas solar conditions are less good on Kalimantan, Sumatra and Papua.



Global Horizontal Irradiation in Indonesia. Source: GHI Solar Map © 2017 Solargis

Due to the Indonesia's geographical location very close to Equator, the solar irradiation is very constant over the year. The graph below shows the average daily irradiation month by month at a location on Northern Java.



Monthly variation of the average daily irradiation on horizon plane (Wh/m2/day) at two locations: Java, North Coast near Cirebon and North-West coast of Sumatra near Bagansiapiapi. The GHI of the Java site is 2025 kWh per m2 per annum and for the Sumatra location 1755 kWh per m2 per annum. Source: PVGIS © Europeen Communitees 2001-2012.

At locations far from Equator, generation may be increased somewhat by tilting the solar power PV panels towards Equator, in Denmark tilting the panels by 41° yields a benefit of around 22%. In Indonesia, the tilt need only be quite small, around 10° on Java, and the resulting benefit is only around 1%. For PV installation on Sumatra and Kalimantan the optimal tilt would be even smaller.

The irradiation to the module can be increased even further by mounting it on a sun-tracking device, this may increase the generation by approximately 22% (based on calculation for the abovementioned Sumatra location with PVGIS).

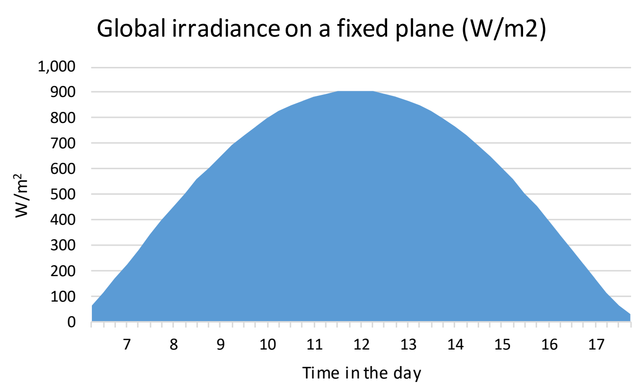
Output
All PV modules generate direct current (DC) electricity as an output, which then needs to be converted to alternating current (AC) by use of an inverter; some modules come with an integrated inverter, so called AC modules, which exhibit certain technical advantages such as the use of standard AC cables, switchgear and a more robust PV module.

The electricity production depends on:

- The amount of solar irradiation received in the plane of the module (see above).
- Installed module generation capacity.
- Losses related to the installation site (soiling and shade).
- Losses related to the conversion from sunlight to electricity (see below).
- Losses related to conversion from DC to AC electricity in the inverter.
- Grid-connection and transformer losses.
- Cable length and cross section, and overall quality of components.

Power generation capacity
The capacity of a solar module is not a fixed value, as it depends on the intensity of the irradiation the module receives as well as the module temperature. For practical reasons the module capacity is therefore referenced to a set of laboratory Standard Test Conditions (STC) which corresponds to an irradiation of 1000 W/m^2 with an AM1.5 spectral distribution perpendicular to the module surface and a cell temperature of 25°C. This STC capacity is referred to as the peak capacity P_p [kWp]. Normal operating conditions will often be different from Standard Test Conditions and the average capacity of the module over the year will therefore differ from the peak capacity. The capacity of the solar module is reduced compared to the P_p value when the actual temperature is higher than 25°C; when the irradiation received is collected at an angle different from normal direct irradiation and when the irradiation is lower than 1000 W/m^2.

In practice, irradiation levels of 1000 W/m^2 are rarely reached, even at locations very close to the Equator like Indonesia. The graph below shows the global irradiance on a fixed plane (W/m^2) during the course of the day in the Java location; for an average daily profile for September - the month with the best solar conditions.



Global irradiance on a fixed plane (W/m^2) during the course of the day in the Java, North Coast near Cirebon; average daily profile for September, the month with the best solar conditions. Source: PVGIS © European Communities 2001-2012.

Besides, some of the electricity generated from the solar modules is lost in the rest of the system e.g. in the DC-to-AC inverter(s), cables, combiner boxes and for larger PV power plants also in the transformer.

The energy production from a PV installation with a peak capacity P_p, can be calculated as:
P_p * Global Horizontal Irradiation * Transposition Factor * (1 - Incident Angle Modifier loss) * (1 - PV systems losses and non-STC corrections) * (1 – Inverter losses) * (1 – Transformer losses).

Wear and degradation
In general, a PV installation is very robust and only requires a minimum of component replacement over the course of its lifetime. The inverter typically needs to be replaced every 10-15 years. For the PV module, only limited physical degradation of a c-Si solar cell will occur. It is common to assign a constant yearly degradation rate of 0.25-0.5% per year to the overall production output of the installation. This degradation rate does not represent an actual physical mechanism. It rather reflects general failure rates following ordinary reliability theory with an initial high (compared to later) but rapidly decreasing "infant mortality", followed by a low rate of constant failures and with an increasing failure rate towards the end-of-life of the various products (ref. 13). Failures in the PV system is typical relate to soldering, cell crack or hot spots, yellowing or delamination of the encapsulant foil, junction box failures, loose cables, hail storm and lightning (ref. 14).

Efficiency and area requirements
The efficiency of a solar module, η_{mod}, expresses the fraction of the power in the received solar irradiation that can be converted to useful electricity. A typical value for commercially available PV modules today is 15-17%, with high-end products already above 20%, when measured at standard test conditions. The module area needed to deliver 1 kWp of peak generation capacity can be calculated as 1 /η_{mod}, and equals 6.25 m^2 by today's standard PV modules.

Ground mounted modules may be located very close to each other in Indonesia, since shadow impacts is not an issue. The ground mounted 1 MW PV plant at Cirata occupies 8.65 m^2 per kWp (1040 kWp using 0.9 Hectare area)

Typical capacities
Typical capacities for PV systems are available from microwatt to gigawatt sizes. But in this context, it is PV systems from a few kilowatts for household systems to several hundred megawatts for utility scale systems. PV systems are inherently modular with a typical module unit size of 200-350 Wp.

Commercial PV systems are typically installed on residential, office or public buildings, and range typically from 50 to 500 kW in size. Such systems are often designed to the available roof area and for a high self-consumption. Utility scale systems or PV power plants will normally be ground mounted and typically range in size from 0.5 MW to ~10 MW. They are often operated by independent power producers that by use of transformers deliver electricity to the medium voltage grid.

Ramping configurations and other power system services
The production from a PV system reflects the yearly and daily variation in solar irradiation. Modern PV inverters may be remotely controlled by grid-operators and can deliver grid-stabilisation in the form of reactive power, variable voltage and power fault ride-through functionality, but the most currently installed PV systems will supply the full amount of available energy to the consumer/grid.
Without appropriate grid regulation in place, high penetration of PV can also lead to unwanted increases in voltage and along with other issues.

Advantages/disadvantages

Advantages:

- PV does not use any fuel or other consumable.
- PV is noiseless (except for fan-noise from inverters).
- PV does not generate any emissions during operation.
- Electricity is produced in the daytime when demand is usually highest.
- With Indonesian solar conditions, the monthly electricity generation from solar PV is quite stable, i.e. no significant seasonal variations.
- PV offers grid-stabilization features.
- PV modules have a long lifetime of more than 30 years and PV modules can be recycled.
- PV systems are modular and easy to install.
- Operation & Maintenance (O&M) of PV plants is simple and limited as there are no moving parts and no wear and tear, with the exception of tracers. Inverters must only be replaced once or twice during the operational life of the installation.
- Large PV power plants can be installed on land that otherwise are of no commercial use (landfills, areas of restricted access or chemically polluted areas).
- PV systems integrated in buildings require no incremental ground space, and the electrical interconnection is readably available at no or small additional cost.

Disadvantages:

- PV systems have relatively high initial costs and a low capacity factor.
- Only produce power when there is sun, meaning necessary for regulation power or storage.
- The space requirement for solar panels per MW is significantly more than for thermal power plants.
- The output of the PV installation can only be adjusted negatively (reduced feed-in) according to demand as production basically follows the daily and yearly variations in solar irradiation.
- Materials abundancy (In, Ga, Te) is of concern for large-scale deployment of some thin-film technologies (CIGS, CdTe).
- Some thin-film technologies do contain small amounts of cadmium and arsenic.
- The best perovskite absorbers contain soluble organic lead compounds, which are toxic and environmentally hazardous at a level that calls for extraordinary precautions.

Environment

The environmental impacts from manufacturing, installing and operating PV systems are limited. Thin film modules may contain small amounts of cadmium and arsenic, but all PV modules as well as inverters are covered by the European Union WEEE directive, whereby appropriate treatment of the products by end-of-life is promoted. The energy payback time of a typical crystalline silicon PV system in Southern Europe is 1.25 years.

Employment

Most parts from solar PV can be produced in Indonesia. PT. LEN is manufacturing PV modules for the Indonesian market. Hanover Solar produce all parts to PV cells on their factory on Batam Island, Indonesia, and have 300 full time employees, producing annually 200 MW solar PV for exporting purposes. The operating Kupang 5 MW project is occupying 10 full time employees for the operation.

Research and development
The PV technology is commercialist, but is still constantly improved and decreased in cost (category 3). A trend in research and development (R&D) activities reflects a change of focus from manufacturing and scale-up issues (2005-2010) and cost reduction topics (2010-2013) to implementation of high efficiency solutions and documentation of lifetime/durability issues (2013-). R&D is primarily conducted in countries where the manufacturing also takes place, such as Germany, China, USA, Taiwan and Japan.

Assumptions and perspectives for further development
The cost of solar PV projects has decreased significantly both in Indonesia and internationally. The reported cost of the Indonesian Kupang PV solar power plant was 2.3 mill. USD/MWp, whereas the Cirate power plant's cost was 2.0 mill USD/MWp. However, PJB, the developer of the 1 MWp Solar PV plant in Cirata, indicate that the capital cost of an ongoing 1 MWp project in Aceh has dropped to around 1.0-1.2 mill. USD/MWp. (ref. 3)

Module prices can be observed at web-sites like http://pvinsights.com/. By mid-July 2017, the average prices of poly silicon solar modules was 0.328 USD/Watt, with prices as low as 0.29 USD/Watt.

A recent review by the Danish Energy Agency and Ea Energy Analyses indicate that the total investment cost of PV plants (modules, inverter and balance of plant) have declined to around 0.80 mill. USD per MWp for utility scale PV plants (MW-size). This price level has been derived from interviews with Danish PV suppliers and a thorough analysis of the recent international tenders for solar PV generation.

The price difference between international levels and the Indonesian context can be expected to diminish as the experience with installation of PV plants in Indonesia increases.

The prices of solar PV modules have declined very significantly historically, a reduction in the order of 23% has been achieved each time the cumulative production has been doubled.

For this assessment is proposed applying a learning rate of 20% for approx. two-thirds of the solar PV system price, which relates to the module and the inverter. This is slightly lower than the historical observed values, but still a high learning rate compared to other technologies. Using a learning rate of 20% for the module and a future deployment of solar PV capacity as projected by the IEA in its global 2 and 4 degree scenarios, we expect PV module costs to drop by around 20-30% between 2020 and 2030 and between 40 and 50% between 2020 and 2050 (ref 5).

For the remaining one third of costs, a more moderate projection development is used, with costs falling by 1% per year until 2020, by 0.75% p.a. between 2020 and 2030 and then by 0.5% p.a.

This leads to the cost projection, presented in the following table, for large-scale solar PV systems, for the international price level as well as the expected level for Indonesia. Historically, the IEA has systematically underestimated the global deployment of PV capacity. Therefore, the cost projection is based on the global demand for PV capacity as depicted in the IEA's 2 DS scenario. Within the next 5 years PV installation costs are expected to follow international development.

Projected investment cost of utility-scale solar PV systems.

Mill. USD/MWp	2020	2030	2050
International price	0.67	0.53	0.41
Indonesian price	0.75	0.55	0.41

Examples of current projects

- Kupang 5 MWp Solar PV, The first IPP Solar PV in Indonesia, Desa Oelpuah, Kupang Regency, East Nusa Tenggara. Inaugurated in December 2015 (ref. 2). Operated by PT LEN.
- Cirata 1 MWp Solar PV, Located in Cirata, West Java, First operating date October 2015 (ref. 3)

References

The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following are sources used:

1. Danish Technology Catalogue "Technology Data for Energy Plants, 2012, PV updated in 2015".
2. PT Len, 2017, "Permasalahan penetrasi solar pv pada sistem grid nasional", Dewan Energi Nasional, June 2017, Industri (Persero)
3. PT. PJB, 2017, "Cirata 1 MW Solar PV O&M and Financial Perspective - Sharing Experience".
4. PVGIS © Europeen Communitees 2001-2012.
5. Ea Energy Analyses, 2017, "Learning curve based forecast of technology costs".
6. Solaren, 2017, http://solaren-power.com/bifacial-modules/, Accessed September 11th 2017.

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* it related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Solar PV - Large scale grid connected								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	0.0002	0.0002	0.0002					C	5
Generating capacity for total power plant (MWe)	10	10	10	1	50	1	50		1
Electricity efficiency, net (%), name plate	-	-	-	-	-	-	-	A	
Electricity efficiency, net (%), annual average	-	-	-	-	-	-	-	A	
Forced outage (%)	-	-	-	-	-	-	-		
Planned outage (weeks per year)	-	-	-	-	-	-	-		
Technical lifetime (years)	25	25	25	15	35	20	40		1,6
Construction time (years)	1.0	0.5	0.5	0.5	1.5	0.25	1		1
Space requirement (1000 m^2/MWe)	9	8	7	7	15	5	15		1
Additional data for non thermal plants									
Capacity factor (%), theoretical	19.4	20.0	20.5	14	22	16	23		1,2
Capacity factor (%), incl. outages	19.4	20.0	20.5	14	22	16	23		1,2
Ramping configurations									
Ramping (% per minute)	-	-	-	-	-	-	-	B	
Minimum load (% of full load)	-	-	-	-	-	-	-	B	
Warm start-up time (hours)	-	-	-	-	-	-	-	B	
Cold start-up time (hours)	-	-	-	-	-	-	-	B	
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	0.83	0.61	0.45	0.70	2.00	0.40	0.80	D,R	1,3,4
- of which equipment	51%	50%	47%						
- of which installation	49%	50%	53%						
Fixed O&M ($/MWe/year)	15,000	12,500	10,500	11,300	18,800	7,900	13,100	Q	5,6
Variable O&M ($/MWh)	0	0	0	0	0	0	0		
Start-up costs ($/MWe/start-up)	0	0	0	0	0	0	0		
Technology specific data									
Global horizontal irradiance (kWh/m2/y)	1,900	1,900	1,900					F	8
DC/AC sizing factor (Wp/W)	1.10	1.10	1.10					G	
Transposition Factor for fixed tilt system	1.01	1.01	1.01					H	8
Performance ratio (%)	0.81	0.84	0.87					I	6
PV module conversion efficiency (%)	19.0%	23.0%	26.0%						6
Availability (%)	100%	100%	100%						6
Inverter lifetime (years)	15	15	15						6
Output									
Full load hours (kWh/kW)	1,700	1,750	1,800					J, L	
Peak power full load hours (kWh/kWp)	1,550	1,600	1,650					K, L	
Financial data									
PV module & inverter cost ($/Wp)	0.38	0.27	0.19						7
Balance Of Plant cost ($/Wp)	0.37	0.28	0.22						7
Specific investment, total system ($/Wp)	0.75	0.55	0.41					M	5,6,9
Specific investment, total system ($/MW)	0.83	0.61	0.45					P	

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Data analysed from www.renewables.ninja for multiple locations in Indonesia.

3 IEA, World Energy Outlook, 2015.

4 Learning curve approach for the development of financial parameters.

5 Cirata 1 MW Solar PV O&M and Financial Perspective, Sharing Experience. PJB.

6 Danish Technology Catalogue *"Technology Data for Energy Plants, 2012, PV updated in 2015.*

7 Permasalahan penetrasi solar pv pada sistem grid nasional, Dewan Energi Nasional, Juni 2017 PT Len Industri (Persero)

8 PVGIS © Europeen Communitees 2001-2012.

9 Learning curve based forecast of technology costs. Ea Energy Analyses, 2017

Notes:

A See "PV module conversion efficiency (%)". The improvement in technology development is also captured in capacity factor, investment costs and space requirement

B The production from a PV system reflects the yearly and daily variation in solar irradiation. It is possible to curtail solar, and this can be done rapidly.

C Listed as MWe. The MWp will be around 10% higher.

D Assumptions described in the section "Assumptions and perspectives for further development"

E Uncertainty (Upper/Lower) is estimated as +/- 25%.

F The global irradiation is a measure of the energy resource potential available and is depended on the exact geographical location. 1900 kWh/m2 corresponds to a good location at Java.

G The DC/AC shown in the table equals module peak capacity divided by plant capacity. The sizing factor is set to the same value for all years, as it is not the technical factors of the system, which determine the sizing factor. The sizing factor is chosen according to the desired utilisation/loading of the inverter which can also reflect a desire to maximise the energy production from a given (restricted) AC-capacity.

H The transposition factor describes the increase in the sunlight energy that can be obtained by tilting the module with respect to horizontal and reduction in received energy when the orientation deviates from South. The TF factor is set to the same value for all years and sizes of the system, as it is not the technical factors of the system, which determine the TF. In Indonesia the TF factor for fixed systems is very low, adding only 0-1 % to the production.

I The performance ratio (PR) of a photovoltaic system is the quotient of alternating current (AC) yield and the nominal yield of the generator's direct current (DC). ThePR factor considers losses due to low irradiance, high temperature and losses in cables and inverter. The performance ratio is lower for PV plants in Indonesia compared to Northern European locations because temperature losses are higher in Indonesia. PJB's on-going project on a location at Simeulue Island, Aceh, expects a performance ratio of 80 %.

J The number of full load hours is calculated based on the other values in the table. The calculation formula is: Full load hours = 1046 * sizing factor * transposition factor * performance ratio

K Also known as the specific yearly energy production (kWh/kWp) of the PV modules. This value is calculated from this formula: Peak power full load hours = 1046 * transposition factor * (1-incident angle modifier loss) * (1-PV system losses etc.) * (1-inverter loss) * (1-AC grid loss).

L Capacity factor = Full load hours / 8760.

M Current international market prices for utility scale PV systems have been estimated based on interviews with Danish developers and an assesment of the prices from Danish and Germany tenders for PV capacity in 2016 and the beginning of 2017. The forecasted internatinal price is based on estimated learning rates for the module and invester (20 % learning rate) and balance of plant (10 % learning rate) and a projection of the cumulated PV capacity based on the IEA's 450 ppm scenario. The share that the PV module and the invester accounts for decreases over time as the result of the higher learning rate compared to the balance of plant. Indonesian prices are assumed to be somewhat higher in the first years thereafter approaching gradually the international level.

P The "specific investment, total system per rated capacity W(AC)" is calculated as "specific investment, total system per Wp(DC)" multiplied by the sizing factor.

Q The cost of O&M includes insurance and regular replacement of inverters and land-lease. Annual O&M is estimated to be 2 % of investment cost per MWp.

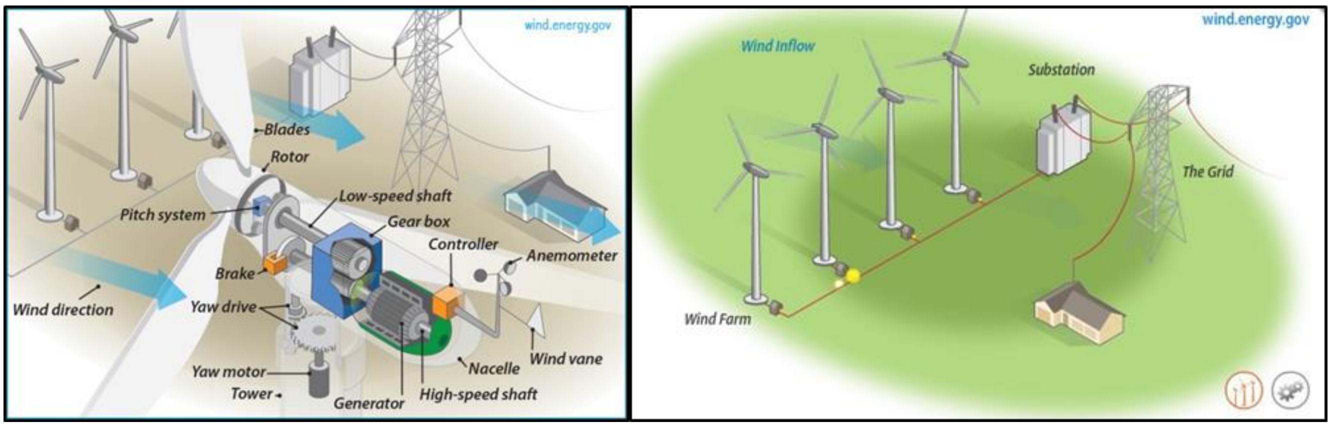
R Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

4. WIND TURBINES

Brief technology description

The typical large onshore wind turbine being installed today is a horizontal-axis, three bladed, upwind, grid connected turbine using active pitch, variable speed and yaw control to optimize generation at varying wind speeds.

Wind turbines work by capturing the kinetic energy in the wind with the rotor blades and transferring it to the drive shaft. The drive shaft is connected either to a speed-increasing gearbox coupled with a medium- or high-speed generator, or to a low-speed, direct-drive generator. The generator converts the rotational energy of the shaft into electrical energy. In modern wind turbines, the pitch of the rotor blades is controlled to maximize power production at low wind speeds, and to maintain a constant power output and limit the mechanical stress and loads on the turbine at high wind speeds. A general description of the turbine technology and electrical system, using a geared turbine as an example, can be seen in the figure below.



General turbine technology and electrical system

Wind turbines are designed to operate within a wind speed range, which is bounded by a low “cut-in” wind speed and a high “cut-out” wind speed. When the wind speed is below the cut-in speed the energy in the wind is too low to be utilized. When the wind reaches the cut-in speed, the turbine begins to operate and produce electricity. As the wind speed increases, the power output of the turbine increases, and at a certain wind speed the turbine reaches its rated power. At higher wind speeds, the blade pitch is controlled to maintain the rated power output. When the wind speed reaches the cut-out speed, the turbine is shut down or operated in a reduced power mode to prevent mechanical damage.

Onshore wind turbines can be installed as single turbines, clusters or in larger wind farms.

Offshore wind farms must withstand the harsh marine environment and this drive costs up. The electrical and mechanical components in the turbines need additional corrosion protection and the offshore foundations are costly. The high cost of installation, results in much higher investment costs than for onshore turbines of similar size. Hoverer, the offshore wind resource is better, and possible onshore sites are limited.

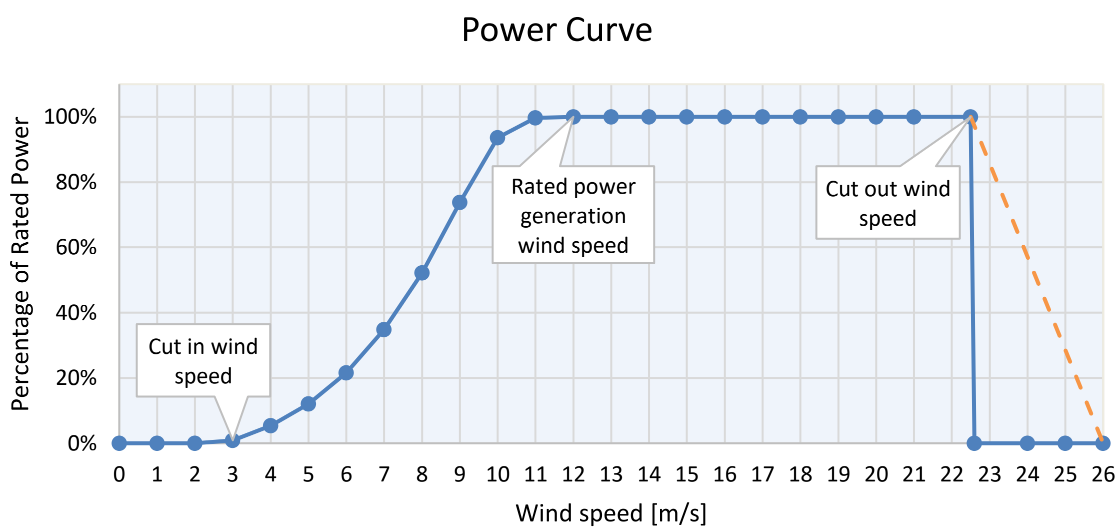
Technological innovations such as floating foundations may reduce the costs in the future and allow offshore wind farms to be commissioned in deep water areas as well, though this technology is not yet deployed on a commercial basis.

Offshore wind farms are typically built with large turbines in considerable numbers.

Commercial wind turbines are operated unattended, and are monitored and controlled by a supervisory control and data acquisition (SCADA) system.

Input
Input is wind.

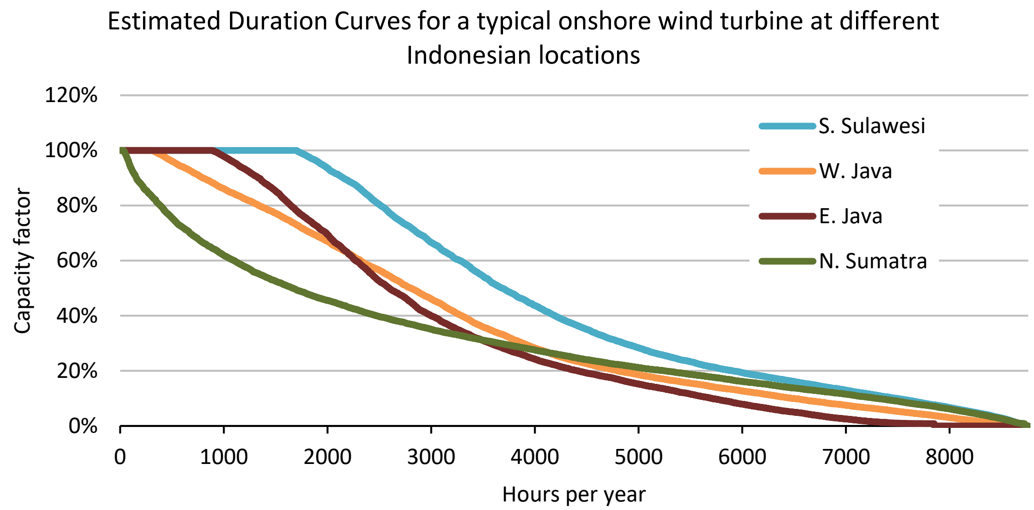
Cut-in wind speed: 3-4 m/s. Rated power generation wind speed is 10-12 m/s. Cut-out or transition to reduced power operation at wind speed around 22-25 m/s for onshore and 25-30 m/s for offshore. In the future, it is expected that manufacturers will apply a soft cut-out for high wind speeds (indicated with dashed orange curve in the figure) resulting in a final cut-out wind speed of up to 30 m/s for onshore wind turbines. The technical solution for this is already available (ref. 17).



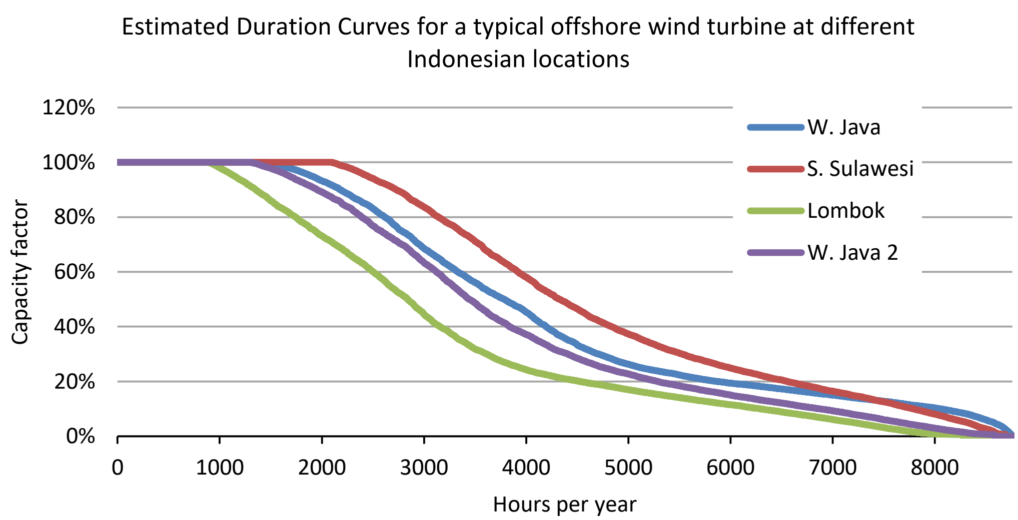
Power curve for a typical wind turbine

Output
The output is electricity.

Generally speaking, the wind resource in Indonesia, is scarce. There are however locations, particularly at Southern Sulawesi and at Java, which demonstrate attractive wind speeds. Based on data from the Indonesian wind resource map the typical capacity factor for a modern onshore turbine located at these good sites in Indonesia will be in the range of 35% corresponding to around 3055 annual full load hours. The estimate is based on the power curve for a low wind speed turbine (with a relative large rotor relative to the capacity of the turbine) and the locations are chosen based on conditions at 100 m hub height. In the figure below, four different duration curves from different locations are plotted, representing the ranges of duration curves found. South Sulawesi is seen to have a good wind recourse with the turbine operating at rated power for around 2000 hours per year. For North Sumatra on the other hand, the duration curve barely reaches its rated power. For offshore, the duration curve looks better with typical capacity factors reaching 49% corresponding to around 4300 annual full load hours.



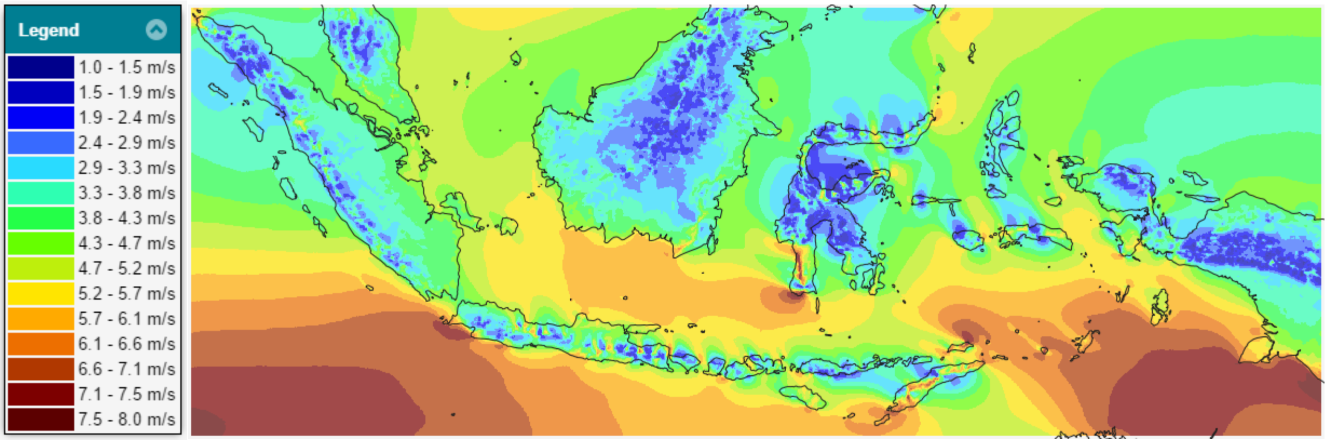
Onshore Duration Curves for different Indonesian locations based on the Indonesian wind resource map at 100 m (ref. 1) and on the power curve for a low wind speed turbine (calculations are based on the power curve of a Vestas V126, 3.3 MW).



Offshore Duration Curves for different Indonesian locations based on the Indonesian wind resource map at 100 m (ref. 1) and on the power curve for a low wind speed turbine (calculations are based on the power curve of a Vestas V136-3.45 MW).

The annual energy output of a wind turbine is strongly dependent on the average wind speed at the turbine location. The average wind speed depends on the geographical location, the hub height, and the surface roughness. Hills and mountains also affect the wind flow, and therefore steep terrain requires more complicated models to predict the wind resource, while the local wind conditions in flat terrain are normally dominated by the surface roughness. Also, local obstacles like forest and, for small turbines, buildings and hedges reduce the wind speed like wakes from neighbouring turbines. Due to the low surface roughness at sea, the variation in wind speed with height is small for offshore locations; the increase in wind speed from 50m to 100m height is around 8%, in comparison to 20% for typical inland locations.

The figure below shows the wind resource map for Indonesia at 100 m altitude. Analysing the potentially good wind turbine sites, the average wind speed for onshore sites is around 6.4 m/s, and for offshore sites the average wind speed is around 7.2 m/s.



Wind resource map for Indonesia in 3 km resolution at 100 m a.g.l. (ref. 1)

Typical capacities

Wind turbines can be categorized according to nameplate capacity. At present time, new onshore installations are in the range of 2 to 6 MW and typical offshore installations are in the range of 3-6 MW. However, turbine capacities of offshore wind turbines are expected to increase in the near future, and current projects in UK is already in 8 MW range (ref. 17).

Two primary design parameters define the overall production capacity of a wind turbine. At lower wind speeds, the electricity production is a function of the swept area of the turbine rotor. At higher wind speeds, the power rating of the generator defines the power output. The interrelationship between the mechanical and electrical characteristics and their costs determines the optimal turbine design for a given site.

The size of wind turbines has increased steadily over the years. Larger generators, larger hub heights and larger rotors have all contributed to increase the electricity generation from wind turbines. Lower specific capacity (increasing the size of the rotor area more than proportionally to the increase in generator rating) improves the capacity factor (energy production per generator capacity), since power output at wind speeds below rated power is directly proportional to the swept area of the rotor. Furthermore, the larger hub heights of larger turbines provide higher wind resources in general.

However, installing large onshore wind turbines requires well-developed infrastructure to be in place, in order to transport the big turbine structures to the site. If the infrastructure is not in place, the installation costs will be much higher, and it might be favourable to invest in smaller turbines that the current infrastructure can manage. However, there are cases where such infrastructure is built together with the project, e.g. the Lake Tukana project of Vestas in Kenya (ref. 17).

Ramping configurations
Electricity from wind turbines is highly variable because it depends on the actual wind resource available. Therefore, the ramping configurations depend on the weather situation. In periods with calm winds (wind speed less than 4-6 m/s) wind turbines cannot offer ramping regulation, with the possible exception of voltage regulation.

With sufficient wind resources available (wind speed higher than 4-6 m/s and lower than 25-30 m/s) wind turbines can always provide down ramping, and in many cases also up regulation, provided the turbine is running in power-curtailed mode (i.e. with an output which is deliberately set below the possible power based on the available wind).

In general, a wind turbine will run at maximum power according to the power curve and up ramping is only possible if the turbine is operated at a power level below the actual available power. This mode of operation is technically possible and in many countries turbines are required to have this feature. However, it is rarely used, since the system operator will typically be required to compensate the owner for the reduced revenue (ref. 2).

Wind turbine generation can be regulated down quickly and this feature is regularly used for grid balancing. The start-up time from no production to full operation depends on the wind resource available.

New types of wind turbines (DFIG and converter based) also have the ability to provide supplementary ancillary services to the grid such as reactive power control, spinning reserve, inertial response, etc.

Advantages/disadvantages
Advantages:
- No emissions of local pollution from operation.
- No emission of greenhouse gasses from operation.
- Stable and predictable costs due to low operating costs and no fuel costs.
- Modular technology allows for capacity to be expanded according to demand, avoiding overbuilds and stranded costs.
- Short lead time compared to most alternative technologies.

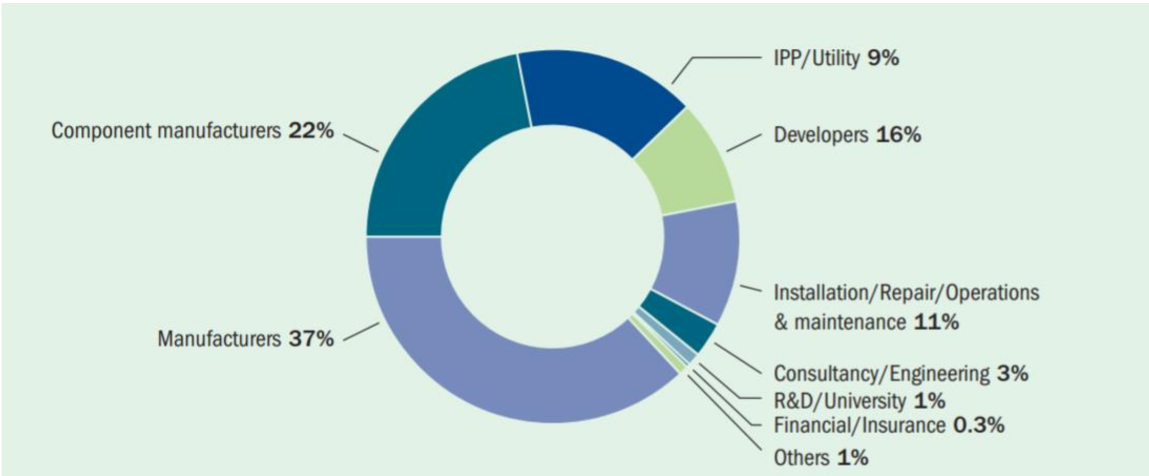
Disadvantages:
- Land use:
    - Wind farm construction may require clearing of forest areas.
    - High population density in on e.g. Java leaves little room for wind farms.
- Variable energy resource.
- Moderate contribution to capacity compared to thermal power plants.
- Need for regulating power.
- Visual impact and noise.

Environment
Wind energy is a clean energy source. The main environmental concern in Indonesia is the removal of vegetation to make room for a wind farms which requires a flat terrain without obstacles.

The environmental impact from the manufacturing of wind turbines is moderate and is in line with the impact of other normal industrial production. The mining and refinement of rare earth metals used in permanent magnets is an area of concern (ref. 3,4,5).

Employment
In India, a total instalment of 22,465 MW onshore wind power, as of 2014, has resulted in an employment of around 48,000 people, meaning that an installed MW of wind power generates around 2.1 jobs locally in onshore wind power (ref. 7,8). The 300 MW Lake Turkana onshore wind project in Kenya is employing 1,500 workers during construction and 150 workers at the operational state, of whom three quarters will be from the local communities, thus generating 0.5 long term jobs per MW. (ref. 15).

The figure below illustrates the distribution of employment in different industries based on wind power in Europe.



Direct employment by type of company based on wind farm projects in Europe. (ref. 6)

Research and development
The wind power technology is commercialist, but is still constantly improved and decreased in cost (category 3). R&D potential (ref. 3,9):

- Reduced investment costs resulting from improved design methods and load reduction technologies.
- More efficient methods to determine wind resources, incl. external design conditions, e.g. normal and extreme wind conditions.
- Improved aerodynamic performance.
- Reduced O&M costs resulting from improvements in wind turbine component reliability.
- Development in ancillary services and interactions with the energy systems.
- Improved tools for wind power forecasting and participation in balancing and intraday markets.

- Improved power quality. Rapid change of power in time can be a challenge for the grid.
- Noise reduction. New technology can decrease the losses by noise reduced mode and possibly utilize good sites better, where the noise sets the limit for number of turbines.
- Storage technologies can improve value of wind power significantly, but is expensive at present.
- Offshore:
    - Further upscaling of wind turbines
    - New foundation types suitable for genuine industrialization
    - Development of 66kV electrical wind farm systems as alternative to present 33 kV.
    - Improved monitoring in operational phase for lowering availability losses and securing optimal operation

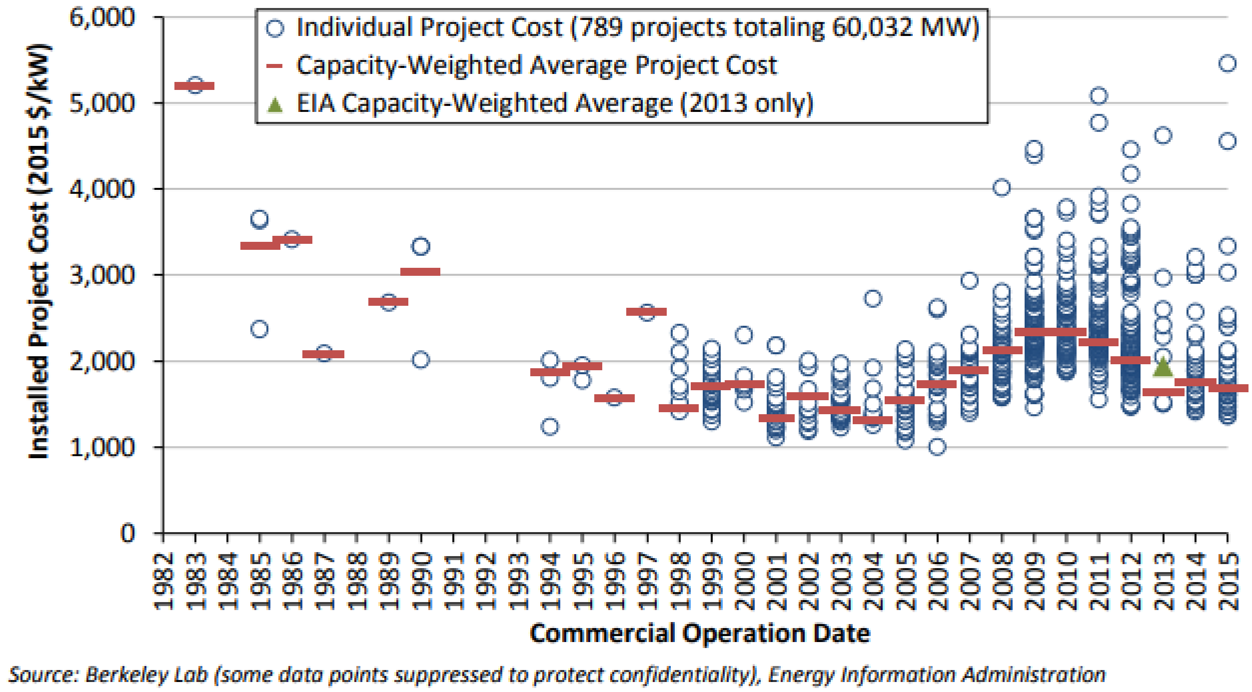
Assumptions and perspectives for further development
The experience with wind power deployment in Indonesia is extremely limited and therefore there is no statistical cost data available that can be relied upon.

Data from the most recent projects in Denmark (2013 and 2014 data) show that the average investment prices for these projects are approximately 1.4 mill. USD/MW (1.2 €/kW) (ref 10). In Germany, average reported costs for 2012 are higher, approx. 1.8 mill. USD/MW (1.5 €/kW) (ref. 11) and probably more representative for the Indonesian context because the wind resource in Germany is moderate on many locations and therefore better suited for low-wind speed turbines.

In the US, average investment cost for onshore wind was just below 2.0 mill. USD/MW in 2012, but since then, costs have decreased to around 1.7 mill. USD/MW by 2015 (ref. 13). Reported costs for India and China have been lower for the period 2013-2014, 1.3-1.4 mill USD/MW, according to IRENA, but substantially higher, approx. 2.6 mill USD/MW (but with very large variation) for “Other Asia” (ref. 14).

In the report Forecasting Wind Energy Costs and Cost Drivers, a non-country specific mean cost for onshore wind of 1.78 mill. USD/MW is provided, representing a mean value for 2014 reported by global wind experts. (ref 16).

Note, that the reported investments above include project development and grid connection.



Development in installed project cost for onshore wind power projects in the US. (ref. 13)

PLN is assuming a planning price of 1.75 mill. USD/MW for Indonesia (ref 12).

Further technological development and cost reductions by global wind turbine manufacturers can be expected to reduce investment costs further towards 2020. Resent development in end 2017 with very low bids in Mexico of around 2 US-cent/kWh points towards a very low cost. On the other hand, the experience with wind turbines in Indonesia is very limited, which is likely to add to costs compared to countries with large-scale deployment. Vestas' assessment is that the investment cost in Indonesia would be 1.4-1.5 mill. USD/MW.

Considering the variation in costs across countries/regions reported above, the value of 1.5 mill. USD/MW is considered the best estimate for a planning cost for onshore large scale wind turbines erected in Indonesia by 2020.

Projection of cost and performance beyond 2020

Onshore wind turbines can be seen as off-the-shelf products, but technology development continues at a considerable pace, and the cost of energy has continued to drop. While price and performance of today's onshore wind turbines are well known, future technology improvements, increased industrialization, learning in general and economies of scale are expected to lead to further reductions in the cost of energy. The annual specific production (capacity factor/full load hours) is expected to continue to increase. The increase in production is mainly expected to be due to lower specific power, but also increased hub heights, especially in the regions with low wind, and improvement in efficiency within the different components is expected to contribute to the increase in production. Based on the projection in ref. 10 we assume a 1.6% increase in capacity factor by 2030 compared to 2020 and 4.8% improvement by 2050.

The predictions of cost reductions are made using the learning curve principle. Learning curves expresses the idea that each time a unit of a particular technology is produced, some learning accumulates which leads to cheaper production of the next unit of that technology. The IEA expects approximately a doubling of the accumulated wind power capacity between 2020 and 2030 and 4-5 times more by 2050 compared to 2020. Assuming a learning of 12.5% per annum this yields a cost reduction of approx. 13% by 2030 and approx. 25% by 2050.

Examples of current projects

'Tolo 1' wind project, 72 MW, Jeneponto, South Sulawesi. Technology: Siemens Gamesa, SWT-3.6-130. The wind farm is developed by Equis Energy and will be installed by late 2017. Commissioning is planned for early 2018.

Sidrap Wind Farm project ,75 MW, located in the municipality of Sidrap, in South Sulawesi, Indonesia. Technology: 30 Gamesa 2.5 MW turbines

References

The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following sources are used:

1. EMD, Wind Energy Resources of Indonesia, http://indonesia.windprospecting.com/
2. Fixed Speed and Variable-Slip Wind turbines Providing Spinning reserves to the Grid, NREL, 2013.
3. Technical University of Denmark, International Energy Report - Wind Energy, 2014.
4. Life Cycle Assessment of Electricity Production from an onshore V112-3.3 MW Wind Plant, June 2014, Vestas Wind Systems A/S.
5. Environmental Product Declaration - SWT-3.2-133, siemens.dk/wind, 2014.
6. Wind at work, Wind energy and job creation in the EU, EWEA, 2008.
7. Renewable Energy and Jobs, Annual Review 2016, IRENA, 2016.
8. Global Wind Statistics 2014, GWEC, 2015.
9. MegaWind, Increasing the Owner's Value of Wind Power Plants in Energy Systems with Large Shares of Wind Energy, 2014.
10. Danish Energy Agency, 2012/2016.Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion
11. IEA Wind Task 26 (2015). Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the European Union, and the United States: 2007–2012.
12. PLN (2017), Data provided by System Planning Division at PLN
13. US Department of Energy (2016). Wind Technologies Market Report 2015.
14. IRENA (2015). Renewable Power Generation Cost in 2014.
15. LEDS Global Partnership (2017), Benefits of low emission development strategies - The case of Kenya's Lake Turkana Wind Power Project.
16. Wiser R, Jenni K, Seel J, Baker E, Hand M. Lantz E,Smith (2016). Forecasting Wind Energy Costs and Cost Drivers: The Views of the World's Leading Experts.
17. Vestas (2017), Information provided by Vestas Sales Division.

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* it related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Wind power - Small onshore wind turbines < 1 MW								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	0.85	0.90	0.95						6
Generating capacity for total power plant (MWe)	13	18	19						5
Electricity efficiency, net (%), name plate	100	100	100					A	
Electricity efficiency, net (%), annual average	100	100	100						
Forced outage (%)	3.0%	2.5%	2.0%						
Planned outage (weeks per year)	0.16	0.16	0.16	0.05	0.26	0.05	0.26		3
Technical lifetime (years)	27	30	30	25	35	25	40		3
Construction time (years)	1.0	1.0	1.0						5, 6
Space requirement (1000 m^2/MWe)	58	58	58						1, 6
Additional data for non thermal plants									
Capacity factor (%), theoretical	35	36	37	20	45	20	45	B	2
Capacity factor (%), incl. outages	34	35	36						
Ramping configurations									
Ramping (% per minute)	-	-	-					F	
Minimum load (% of full load)	-	-	-					F	
Warm start-up time (hours)	-	-	-						
Cold start-up time (hours)	-	-	-						
Environment									
PM 2.5 (gram per Nm^3)	0	0	0						
SO_2 (degree of desulphuring, %)	0	0	0						
NO_X (g per GJ fuel)	0	0	0						
CH_4 (g per GJ fuel)	0	0	0						
N_2O (g per GJ fuel)	0	0	0						
Financial data									
Nominal investment (M$/MWe)	4.00	3.48	2.96					D	5, 6
- of which equipment	55%	55%	55%					C	
- of which installation	45%	45%	45%					C	
Fixed O&M ($/MWe/year)	73,200	63,700	54,200						4
Variable O&M ($/MWh)	0	0	0						4
Start-up costs ($/MWe/start-up)	0	0	0						
Technology specific data									

References:

1 PLN data provided by Pak Arief Sugiyanto, System Planning Devision at PLN. Supported by review of international price data, cf. technology description.

2 Wind Energy Resources of Indonesia 2014-2017, EMD International A/S, Denmark, financed by the Environmental Support Programme 3 (ESP3) / Danida.

3 Danish Energy Agency, 2012/2016.Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion

4 IEA Wind Task 26, 2015, "Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the EU, and the USA: 2007–2012".

5 Case: Faroe Islands, Húsahagi 2014

6 Case: Kenya, Lake Turkana, 2014-2017

Notes:

A The efficiency is defined as 100%. The improvement in technology development is captured in capacity factor, investment cost and space requirement.

B The capacity factor provided represent an average of good locations in Indonesia, see presentation in catalogue text. As mentioned in the description, generelly speaking, the wind resource in Indonesia is scarce.

C Equipment: Cost of turbines including transportation. Installation: Electricical infrastructure of turbine, civil works, grid connection, planning and management. The split of cost may vary considerably from project to project.

D The IEA expects approximately a doubling of the accumulated wind power capacity between 2020 and 2030 and 4-5 times more by 2050 compared to 2020. Assuming a learning of 12.5 % per annum this yields a cost reduction of approx. 13 % by 2030 and approx. 25 % by 2050.

E Uncertainty (Upper/Lower) is estimated as +/- 25%.

F With sufficient wind resource available (wind speed higher than 4-6 m/s and lower than 25-30 m/s) wind turbines can always provide down regulation, and in many cases also up regulation, provided the turbine is running in power-curtailed mode (i.e. with an output which is deliberately set below the possible power based on the available wind).

Technology	Wind power - Onshore								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	3.5	4.0	5.0						3
Generating capacity for total power plant (MWe)	70	80	100						1
Electricity efficiency, net (%), name plate	100	100	100					A	
Electricity efficiency, net (%), annual average	100	100	100						
Forced outage (%)	2.5%	2.0%	2.0%						
Planned outage (weeks per year)	0.16	0.16	0.16	0.05	0.26	0.05	0.26		3
Technical lifetime (years)	27	30	30	25	35	25	40		3
Construction time (years)	1.5	1.5	1.5						1
Space requirement (1000 m^2/MWe)	14	14	14						1
Additional data for non thermal plants									
Capacity factor (%), theoretical	35	36	37	20	45	20	45	B	
Capacity factor (%), incl. outages	34	35	36						
Ramping configurations									
Ramping (% per minute)	-	-	-					F	
Minimum load (% of full load)	-	-	-					F	
Warm start-up time (hours)	-	-	-						
Cold start-up time (hours)	-	-	-						
Environment									
PM 2.5 (gram per Nm^3)	0	0	0						
SO_2 (degree of desulphuring, %)	0	0	0						
NO_X (g per GJ fuel)	0	0	0						
CH_4 (g per GJ fuel)	0	0	0						
N_2O (g per GJ fuel)	0	0	0						
Financial data									
Nominal investment (M$/MWe)	1.50	1.31	1.11	1.4	2.0	1.0	1.5	D	1
- of which equipment	65%	65%	65%					C	2, 3
- of which installation	35%	35%	35%					C	2, 3
Fixed O&M ($/MWe/year)	60,000	52,200	44,400	30,000	70,000	25,000	60,000		4
Variable O&M ($/MWh)	0	0	0						4
Start-up costs ($/MWe/start-up)	0	0	0						
Technology specific data									

References:

1 PLN data provided by the System Planning Division at PLN. Supported by review of international price data, cf. technology description.

2 IRENA (2015). Renewable Power Generation Cost in 2014

3 Danish Energy Agency, 2012/2016.Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion

4 IEA Wind Task 26, 2015, "Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the EU, and the USA: 2007–2012".

5 Vestas data provided by the Sales Division for the Asian Pacific.

Notes:

A The efficiency is defined as 100%. The improvement in technology development is captured in capacity factor, investment cost and space requirement.

B The capacity factor provided represent an average of good locations in Indonesia, see presentation in catalogue text. As mentioned in the description, generelly speaking, the wind resource in Indonesia.

C Equipment: Cost of turbines including transportation. Installation: Electricical infrastructure of turbine, civil works, grid connection, planning and management. The split of cost may vary considerably from project to project.

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F With sufficient wind resource available (wind speed higher than 4-6 m/s and lower than 25-30 m/s) wind turbines can always provide down regulation, and in many cases also up regulation, provided the turbine is running in power-curtailed mode (i.e. with an output which is deliberately set below the possible power based on the available wind).

Technology	Wind power - Offshore								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	8.0	10.0	12.0						3
Generating capacity for total power plant (MWe)	240	300	360						
Electricity efficiency, net (%), name plate	100	100	100					A	
Electricity efficiency, net (%), annual average	100	100	100					A	
Forced outage (%)	4.0%	3.0%	3.0%						3
Planned outage (weeks per year)	0.16	0.16	0.16						3
Technical lifetime (years)	27	30	30	20	35	20	35		3
Construction time (years)	3.0	2.5	2.5	1.5	4	1.5	4		3
Space requirement (1000 m^2/MWe)	185	185	185	168	204	168	204		3
Additional data for non thermal plants									
Capacity factor (%), theoretical	50	51	52	20	45	20	45	B	2
Capacity factor (%), incl. outages	47.9	49.1	50.7						
Ramping configurations									
Ramping (% per minute)	-	-	-					F	
Minimum load (% of full load)	-	-	-					F	
Warm start-up time (hours)	-	-	-						
Cold start-up time (hours)	-	-	-						
Environment									
PM 2.5 (gram per Nm^3)	0	0	0						
SO_2 (degree of desulphuring, %)	0	0	0						
NO_X (g per GJ fuel)	0	0	0						
CH_4 (g per GJ fuel)	0	0	0						
N_2O (g per GJ fuel)	0	0	0						
Financial data									
Nominal investment (M$/MWe)	3.50	3.05	2.59	2.80	3.40	1.80	2.70	D	3
- of which equipment	45%	45%	45%					C	3
- of which installation	55%	55%	55%					C	3
Fixed O&M ($/MWe/year)	72,600	64,700	55,000	58,200	71,200	38,000	57,200		4
Variable O&M ($/MWh)	5.5	4.8	3.9	4.3	5.3	2.6	3.8		4
Start-up costs ($/MWe/start-up)	0	0	0						
Technology specific data									

References:

1 PLN data provided by Pak Arief Sugiyanto, System Planning Devision at PLN. Supported by review of international price data, cf. technology description.

2 Wind Energy Resources of Indonesia 2014-2017, EMD International A/S, Denmark, financed by the Environmental Support Programme 3 (ESP3) / Danida.

3 Danish Energy Agency, 2012/2016.Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion

4 IEA Wind Task 26, 2015, "Wind Technology, Cost, and Performance Trends in Denmark, Germany, Ireland, Norway, the EU, and the USA: 2007–2012".

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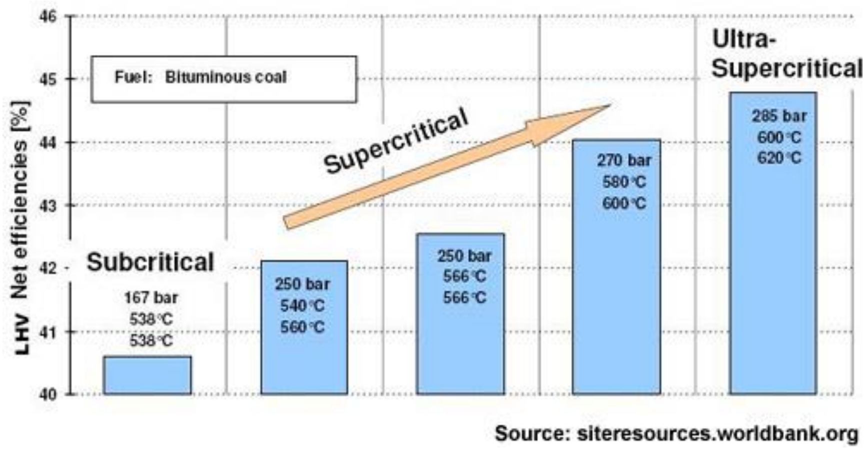
5. COAL POWER PLANT

Brief technology description
We distinguish between three types of coal fired power plants; subcritical, supercritical and ultra-supercritical. The names refer to the state (temperature and pressure) of where the steam in cycle exist. The main differences are the efficiencies of the plants, as shown in the figure below.

Subcritical is below 200 bars and 540°C. Both supercritical and ultra-supercritical plants operate above the water-steam critical point, which requires pressures of more than 221 bars (by comparison, a subcritical plant will generally operate at a pressure of around 165 bars). Above the water-steam critical point, water will change from liquid to steam without boiling – that is, there is no observed change in state and there is no latent heat requirement. Supercritical designs are employed to improve the overall efficiency of the generator. There is no standard definition for ultra-supercritical versus supercritical. The term 'ultra-supercritical' is used for plants with steam temperatures of approximately 600°C and above (ref. 1).



Differences between sub-, super-, and ultra-supercritical plant (ref. 6).

Input
The process is primarily based on coal, but will be applicable to other fuels such as wood pellets and natural gas.

Output
Power. The auxiliary power need for a 500 MW plant is 40-45 MW, and the net electricity efficiency is thus 3.7-4.3 percentage points lower than the gross efficiency (ref. 2).

Typical capacities
Subcritical power plant can be from 30 MW and upwards. Supercritical and ultra-supercritical power plants have to be larger and are usually from 400 MW to 1500 MW (ref. 3).

Ramping configurations
Pulverized fuel power plants are able to deliver both frequency control and load support. Advanced units are in general able to deliver 5% of their rated capacity as frequency control within 30 seconds at loads between 50% and 90%.

This fast load control is achieved by utilizing certain water/steam buffers within the unit. The load support control takes over after approximately 5 minutes, when the frequency control function has utilized its water/steam buffers. The load support control is able to sustain the 5% load rise achieved by the frequency load control and even further to increase the load (if not already at maximum load) by running up the boiler load.

Negative load changes can also be achieved by by-passing steam (past the turbine) or by closure of the turbine steam valves and subsequent reduction of boiler load.

Advantages/disadvantages

Advantages:

- Mature and well-known technology.
- The efficiencies are not reduced as significantly at part load compared to full load as with combined cycle-plants.

Disadvantages:

- Coal fired power plants emit high concentrations of NOx, SO2 and particle matter (PM), which have high societal costs in terms of health problems and in the worst case death.
- The burning of coal is the biggest emitter per CO_2 emission per energy unit output, even for a supercritical power plant.
- Coal fired power plants using the advanced steam cycle (supercritical) possess the same fuel flexibility as the conventional boiler technology. However, supercritical plants have higher requirements concerning fuel quality. Inexpensive heavy fuel oil cannot be burned due to materials like vanadium, unless the steam temperature (and hence efficiency) is reduced, and biomass fuels may cause corrosion and scaling, if not handled properly.

Environment

The burning and combustion of coal creates the products CO_2, CO, H_2O, SO_2, NO_2, NO and other particle matter (PM). CO, NOx and SO_2 are locally poison for the brain and lung, causing headaches and shortness of breath, and in worst case death. CO_2 is causing global warming and thereby climate changes. (ref. 3)

It is possible to implement filters for NOx and SO_2. In Indonesia, it is currently the Ministry of Environment Decree no. 21/2008 on stationary sources of air pollutants that states the maximum pollution from fossil fuel fired power plants.

Employment

The PLTU Adipala 700 MW supercritical power plant have employed 2000 full time employees in the construction phase. Hereof 500 was hired from the local villages.

Research and development

Conventional supercritical coal technology is fairly well established and so there appear to be no major breakthroughs ahead (category 4). There is very limited scope to improve the cycle thermodynamically. It is more likely that the application of new materials will allow higher efficiencies, though this is unlikely to come at a significantly lower cost (ref. 4).

Examples of current projects

Adipala supercritical 700 MW power plant on Java commissioned in 2016.

References

The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following sources are used:

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Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Subcritical coal power plant								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	150	150	150	100	200	100	200		1
Generating capacity for total power plant (MWe)	150	150	150	100	200	100	200		1
Electricity efficiency, net (%), name plate	35	36	37	30	38	33	39		1,2,3
Electricity efficiency, net (%), annual average	34	35	36	29	37	32	38		1,2,3
Forced outage (%)	7	5	3	5	20	2	7	A	1
Planned outage (weeks per year)	6	5	3	3	8	2	4	A	1
Technical lifetime (years)	30	30	30	25	40	25	40		1
Construction time (years)	3	3	3	2	4	2	4		1
Space requirement (1000 m^2/MWe)	-	-	-	-	-	-	-		
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configuration									
Ramping (% per minute)	3.5	3.5	3.5	2	4	2	4	B	1
Minimum load (% of full load)	30	25	20	25	50	10	30	A	1
Warm start-up time (hours)	3	3	3	1	5	1	5	B	1
Cold start-up time (hours)	8	8	8	5	12	5	12	B	1
Environment									
PM 2.5 (mg per Nm^3)	150	100	100	50	150	20	100	A,F	2,4
SO_2 (degree of desulphuring, %)	73	80	95	73	95	73	95	A,C,D	2,4
NO_X (g per GJ fuel)	263	150	38	263	263	263	263	A,D	2,4
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	1.65	1.60	1.55	1.05	1.70	1.05	1.70	E,H	1,3
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	45,250	43,900	42,500	33,900	56,600	31,900	53,100	G	1,3
Variable O&M ($/MWh)	0.13	0.12	0.12	0.09	0.16	0.09	0.15	G	1,3
Start-up costs ($/MWe/start-up)	110	110	110	50	200	50	200		5

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Platts Utility Data Institute (UDI) World Electric Power Plant Database (WEPP)

3 Learning curve approach for the development of financial parameters.

4 Maximum emission from Minister of Environment Regulation 21/2008

5 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.

Notes:

A Assumed gradidual improvement to international standard in 2050.

B Assumed no improvement for regulatory capability.

C Indonesian sulphur content in coal is up to 360 g/GJ. Conversion factor 0.35 to mg/Nm3 yields 1030 mg/Nm3. With a max of 750 mg/Nm3 then gives a % of desulphuring of 73%.

D Calculated from a max of 750 mg/Nm3 to g/GJ (conversion factor 0.35 from Pollution Prevention and Abatement Handbook, 1998)

E For economy of scale a proportionality factor, a, of 0.8 is suggested.

F Uncertainty Upper is from regulation. Lower is from current standards in Japan (2020) and South Korea (2050).

G Uncertainty (Upper/Lower) is estimated as +/- 25%.

H Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

Technology	Supercritical coal power plant								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	600	600	600	300	800	300	800		1
Generating capacity for total power plant (MWe)	600	600	600	300	800	300	800		1
Electricity efficiency, net (%), name plate	38	39	40	33	40	35	42		1,3,6,7
Electricity efficiency, net (%), annual average	37	38	39	33	40	35	42		1,3
Forced outage (%)	7	6	3	5	15	2	7	A	1
Planned outage (weeks per year)	7	5	3	3	8	2	4	A	1
Technical lifetime (years)	30	30	30	25	40	25	40		1
Construction time (years)	4	3	3	3	5	2	4	A	1
Space requirement (1000 m^2/MWe)	-	-	-	-	-	-	-		
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configuration									
Ramping (% per minute)	4	4	4	3	4	3	4	B	1
Minimum load (% of full load)	30	25	20	25	50	10	30	A	1
Warm start-up time (hours)	4	4	4	2	5	2	5	B	1
Cold start-up time (hours)	12	12	12	6	15	6	12	B	1
Environment									
PM 2.5 (mg per Nm^3)	150	100	100	50	150	20	100	F	2,4
SO_2 (degree of desulphuring, %)	73	73	73	73	95	73	95	C,D	2,4
NO_X (g per GJ fuel)	263	263	263	263	263	263	263	D	2,4
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	1.40	1.36	1.32	1.05	1.75	0.99	1.65	E,G,H	1,3,6,7
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	41,177	39,900	38,700	30,900	51,500	29,000	48,400	G	1,3,6,7
Variable O&M ($/MWh)	0.12	0.12	0.11	0.09	0.15	0.08	0.14	G	1,3
Start-up costs ($/MWe/start-up)	50	50	50	40	100	40	100		5

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Platts Utility Data Institute (UDI) World Electric Power Plant Database (WEPP)

3 Learning curve approach for the development of financial parameters.

4 Maximum emission from Minister of Environment Regulation 21/2008

5 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.

6 IEA, Projected Costs of Generating Electricity, 2015.

7 IEA, World Energy Outlook, 2015.

Notes:

A Assumed gradidual improvement to international standard in 2050.

B Assumed no improvement for regulatory capability.

C Indonesian sulphur content in coal is up to 360 g/GJ. Conversion factor 0.35 to mg/Nm3 yields 1030 mg/Nm3. With a max of 750 mg/Nm3 then gives a % of

D Calculated from a max of 750 mg/Nm3 to g/GJ (conversion factor 0.35 from Pollution Prevention and Abatement Handbook, 1998)

E For economy of scale a proportionality factor, a, of 0.85 is suggested.

F Uncertainty Upper is from regulation. Lower is from current standards in Japan (2020) and South Korea (2050).

G Uncertainty (Upper/Lower) is estimated as +/- 25%.

H Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

Technology	Ultra-supercritical coal power plant								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	1000	1000	1000	700	1200	700	1200		1
Generating capacity for total power plant (MWe)	1000	1000	1000	700	1200	700	1200		1
Electricity efficiency, net (%), name plate	43	44	45	40	45	42	47		1,3,6,7
Electricity efficiency, net (%), annual average	42	43	44	40	45	42	47		1,3
Forced outage (%)	7	6	3	5	15	2	7	A	1
Planned outage (weeks per year)	7	5	3	3	8	2	4	A	1
Technical lifetime (years)	30	30	30	25	40	25	40		1
Construction time (years)	4	3	3	3	5	2	4	A	1
Space requirement (1000 m^2/MWe)	-	-	-	-	-	-	-		
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configuration									
Ramping (% per minute)	5	5	5	4	5	4	5	B	1
Minimum load (% of full load)	30	25	20	25	50	10	30	A	1
Warm start-up time (hours)	4	4	4	2	5	2	5	B	1
Cold start-up time (hours)	12	12	12	6	15	6	12	B	1
Environment									
PM 2.5 (mg per Nm^3)	150	100	100	50	150	20	100	F	2,4
SO_2 (degree of desulphuring, %)	73	73	73	73	95	73	95	C,D	2,4
NO_X (g per GJ fuel)	263	263	263	263	263	263	263	D	2,4
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	1.52	1.48	1.43	1.14	1.91	1.07	1.79	E,G,H	1,3,6,7
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	56,580	54,900	53,200	42,400	70,700	39,900	66,500	G	1,3,6,7
Variable O&M ($/MWh)	0.11	0.11	0.10	0.08	0.14	0.08	0.13	G	1,3
Start-up costs ($/MWe/start-up)	50	50	50	40	100	40	100		5

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Platts Utility Data Institute (UDI) World Electric Power Plant Database (WEPP)

3 Learning curve approach for the development of financial parameters.

4 Maximum emission from Minister of Environment Regulation 21/2008

5 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.

6 IEA, Projected Costs of Generating Electricity, 2015.

7 IEA, World Energy Outlook, 2015.

Notes:

A Assumed gradidual improvement to international standard in 2050.

B Assumed no improvement for regulatory capability.

C Indonesian sulphur content in coal is up to 360 g/GJ. Conversion factor 0.35 to mg/Nm3 yields 1030 mg/Nm3. With a max of 750 mg/Nm3 then gives a % of

D Calculated from a max of 750 mg/Nm3 to g/GJ (conversion factor 0.35 from Pollution Prevention and Abatement Handbook, 1998)

E For economy of scale a proportionality factor, a, of 0.85 is suggested.

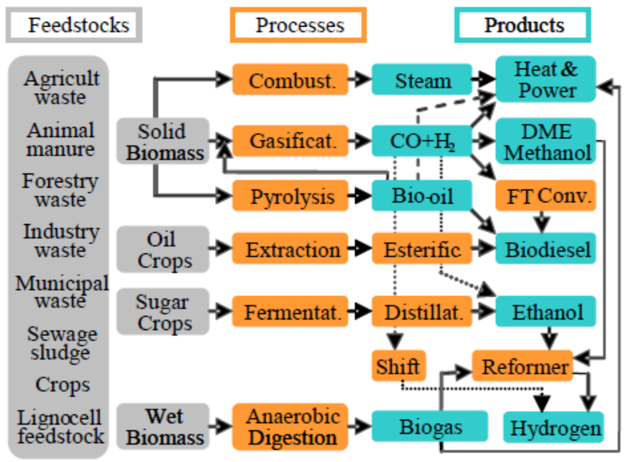
F Uncertainty Upper is from regulation. Lower is from current standards in Japan (2020) and South Korea (2050).

G Uncertainty (Upper/Lower) is estimated as +/- 25%.

H Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

6. BIOMASS POWER PLANT

Brief technology description
Biomass can be used to produce electricity or fuels for transport, heating and cooking. The figure below shows the varies products from biomass. We will in this chapter focus on the solid biomass for combustion to power generation.

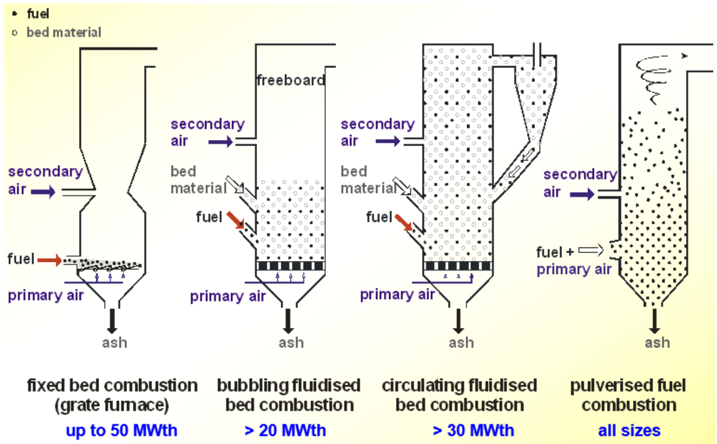


Biomass conversion paths (ref. 1)

The technology used to produce electricity in biomass power plants depends on the biomass resources. Due to the lesser heating value of biomass compared to coal, the electric efficiency is lower – typically 15-35% (ref. 2).

Direct combustion of biomass is generally based on the Rankine cycle, where a steam turbine is employed to drive the generator, similar to a coal fired power plant. A flue gas heat recovery boiler for recovering and pre-heating the steam is sometimes added to the system. This type of system is well developed, and available commercially around the world. Most biomass power plants today are direct-fired (ref. 3). In direct combustion, steam is generated in boilers that burn solid biomass, which has been suitably prepared (dried, baled, chipped, formed into pellets or briquettes or otherwise modified to suit the combustion technology) through fuel treatment and a feed-in system. Direct combustion technologies may be divided into fixed bed, fluidized bed, and dust combustion. In dust combustion, the biomass is pulverized or chopped and blown into the furnace, possibly in combination with a fossil fuel (see figure below).

Indonesia has abundant biomass resources which has potential for generation of electricity. The sources include palm oil, sugar cane, rubber, coconut, paddy, corn, cassava, cattle, and municipal waste. According to MEMR (ref. 7), the total biomass potential is amounted to 33 GW which is widely spread over all islands in Indonesia. The table below show the distribution of biomass potentials. From the 33 GW of biomass potential, about 39% comes from palm oil, 30% from paddy, 9% from rubber, 6% from municipal waste, 5% from corn, 4% from wood, and 4% from sugar cane.



Technologies for industrial biomass combustion (ref. 4)

Biomass resources potential (ref. 8)

No	Island	Potential (GW)
1	Sumatera	15.59
2	Jawa Bali Madura	9.22
3	Kalimantan	5.06
4	Sulawesi	1.94
5	Nusa Tenggara	0.64
6	Maluku	0.07
7	Papua	0.15
Total		32.65

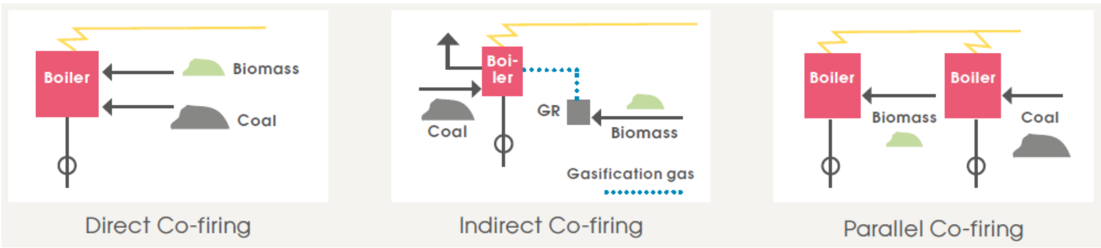
Heating values of different biomass fuel types (ref. 9)

Type	LHV (GJ/ton)	Moisture (%)	Ash (%)
Bagasse	7.7 – 8.0	40 – 60	1.7 – 3.8
Cocoa husks	13 – 16	7 – 9	7-14
Coconut shells	18	8	4
Coffee husks	16	10	0.6
Cotton residues			
- Stalks	16	10 – 20	0.1
- Gin trash	14	9	12
Maize			
- Cobs	13 – 15	10 – 20	2
- Stalks			3 – 7
Palm-oil residues			
- Empty fruit bunchs	5.0	63	5
- Fibers	11	40	
- Shells	15	15	
Debris	15	15	
Peat	9.0 – 15	13 – 15	1 – 20
Rice husks	13	9	19
Straw	12	10	4.4
Wood	8.4 – 17	10 – 60	0.25 – 1.7

The table above shows that the caloric values of the biomass feedstocks range from 5 – 18 GJ/ton, with the palm oil empty fruit brunches (EFB) as the lowest and coconut shells as the highest.

Total current installed capacity of biomass (dedicated) power plants in Indonesia for 2016 is 1,788 MW. Most of these power plants are operated by industries using various types of biomass as fuels, such as palm oil EFB (empty fruit bunch), municipal waste, palm oil mill effluent (POME), palm kernel shells (PKS), pulp and paper industry waste, and sugar cane industry waste.

Co-firing with coal
There are three possible technology set-ups for co-firing coal and biomass: direct, indirect and parallel co-firing (see figure below). Technically, it is possible to co-fire up to about 20% biomass capacity without any technological modifications; however, most existing co-firing plants use up to about 10% biomass. The co-firing mix also depends on the type of boiler available. In general, fluidized bed boilers can substitute higher levels of biomass than pulverized coal-fired or grate-fired boilers. Dedicated biomass co-firing plants can run up to 100% biomass at times, especially in those co-firing plants that are seasonally supplied with large quantities of biomass (ref. 5).



Different biomass co-firing configurations (ref. 6)

Combustion can in general be applied for biomass feedstock with moisture contents between 20 – 60% depending om the type of biomass feedstock and combustion technology.

Input
Biomass; e.g. residues from industries (wood waste, empty fruit bunchs, coconut shell, etc.), wood chips (collected in forests), straw, and energy crops.

Wood is usually the most favorable biomass for combustion due to its low content of ash and nitrogen. Herbaceous biomass like straw and miscanthus have higher contents of N, S, K, Cl etc. that leads to higher primary emissions of NOx and particulates, increased ash, corrosion and slag deposits. Flue gas cleaning systems as ammonia injection (SNCR), lime injection, back filters, DeNOx catalysts etc. can be applied for further reduction of emissions.

Other exotic biomasses as empty fruit bunch pellets (EFB) and palm kernel shells (PKS) are available in the market.

Output
Electricity (and heat if there is demand for it).

Typical capacities
Large: bigger than 50 MWe
Medium: 10 – 50 MWe.

Small: 1 – 10 MWe.

Ramping configuration
The plants can be ramped up and down. Medium and small size biomass plants with drum type boilers can be operated in the range from 40-100% load. Often plants are equipped with heat accumulators allowing the plant to be stopped daily.

Advantages/disadvantages
Advantages:

- Mature and well-known technology.
- No emission of greenhouse gasses from operation.
- Using biomass waste will usually be cheap.

Disadvantages:

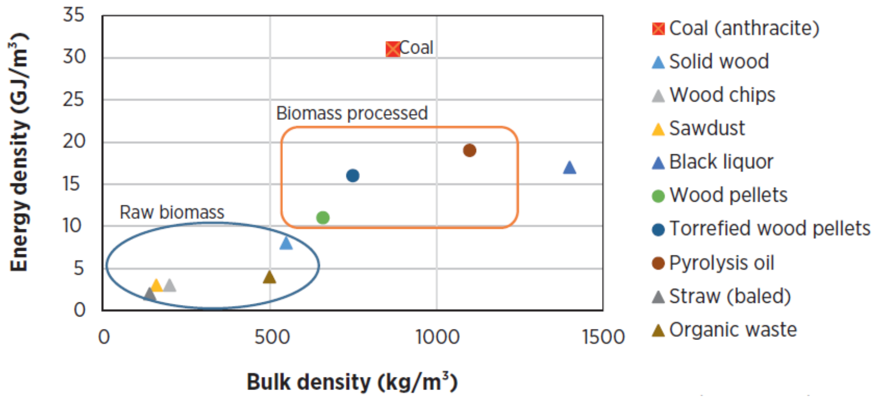
- The availability of biomass feedstock is locally dependent.
- In the low capacity range (less than 10 MW) the scale of economics is quite considerable.
- When burning biomass in a boiler, the chlorine and sulfur in the fuel end up in the combustion gas and erode the boiler walls and other equipment. This can lead to the failure of boiler tubes and other equipment, and the plant must be shut down to repair the boiler.
- Fly ash may stick to boiler tubes, which will also lower the boiler's efficiency and may lead to boiler tube failure. With furnace temperatures above 1000°C, empty fruit bunches, cane trash, and palm shells create more melting ashes than other biomass fuels. The level for fused ash should be no more than 15% in order to keep the boiler from being damaged. (ref. 9)

Environment
The main ecological footprints from biomass combustion are persistent toxicity, climate change, and acidification. However, the footprints are small (ref. 10).

Research and development
Biomass power plants are a mature technology with limited development potential (category 4). However, in Indonesia, using biomass for power generation is relatively new.

Some 85% of biomass energy is consumed in Indonesia for traditional uses, for example cooking with very low efficiency (10%-20%) while modern uses of biomass for heat and power generation include mainly high-efficiency, direct biomass combustion, co-firing with coal and biomass gasification. These modern uses, especially direct combustion, are increasing in Indonesia now. Solid and liquid palm oil wastes seem to be the most favorable choices for biomass feedstock due to the easy access and handling and also the availability.

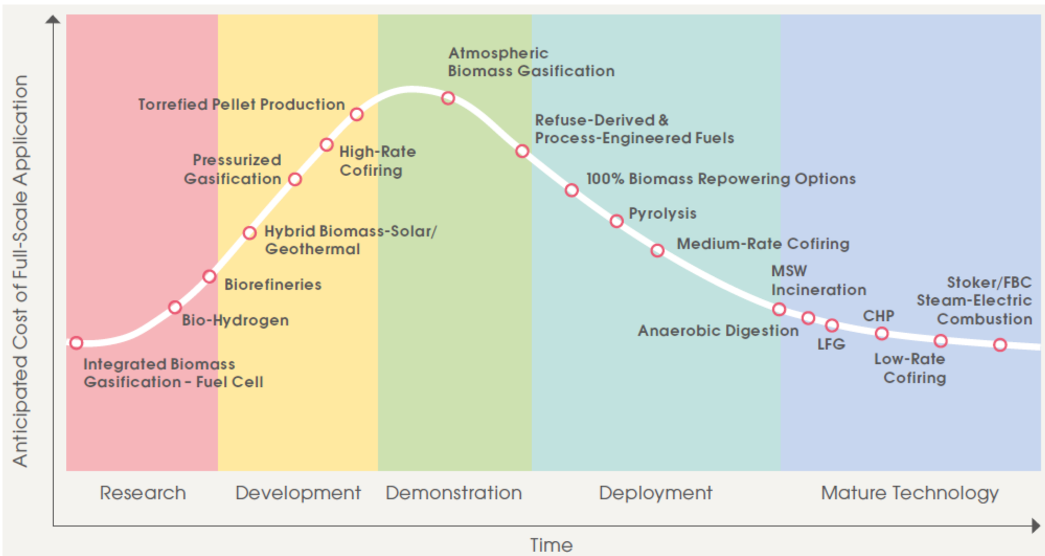
Direct, traditional uses of biomass for heating and cooking applications rely on a wide range of feedstock and simple devices, but the energy efficiency of these applications is very low because of biomass moisture content, low energy density and the heterogeneity of the basic input. A range of pre-treatment and upgrading technologies have been developed in order to improve biomass characteristics and make handling, transport, and conversion processes more efficient and cost effective. Most common forms of pre-treatment include: drying, pelletization and briquetting, torrefaction and pyrolysis.



Energy density of biomass and coal (ref. 11)

MSW incineration, anaerobic digestion, land-fill gas, combined heat and power and combustion are examples of biomass power generation technologies which are already mature and economically viable. Biomass gasification and pyrolysis are some of the technologies which are likely to be developed commercially in the future.

Gasifier technologies offer the possibility of converting biomass into a producer gas, which can be burned in simple or combined-cycle gas turbines at higher efficiencies than the combustion of biomass to drive a steam turbine. Although gasification technologies are commercially available, more needs to be done in terms of R&D and demonstration to promote their widespread commercial use.



Biomass power generation technology maturity status (ref. 12)

Biomass pyrolysis is the thermal decomposition of biomass in the absence of oxygen. The products of decomposition are solid char, a liquid known as bio-oil or pyrolysis oil and a mixture of combustible gases. The relative proportions of solid, liquid and gaseous products are controlled by process temperature and residence time, as indicated in the table below.

Bio-oil has a lower heating value of about 16 MJ/kg and can after suitable upgrading be used as fuel in boilers, diesel engines and gas turbines for electricity or CHP generation. As a liquid with higher energy density than the solid biomass from which it is derived, bio-oil provides a means of increasing convenience and decreasing costs of biomass transport, storage and handling.

Phase makeup of biomass pyrolysis products for different operational modes (ref. 13)

Mode	Conditions	Composition		
		Liquid	Char	Gas
Fast pyrolysis	Moderate temperature, short residence time	75%	12%	13%
Carbonization	Low temperature, very long residence time	30%	35%	35%
Gasification	High temperature, long residence time	5%	10%	85%

Examples of current projects

Sinar Mas group, owner of OKI pulp and paper industry in Sumatera Selatan, built a big biomass power plant with an installed capacity of 4 x 125 MW. The boiler of the power plant has been tested using waste from Sinar Mas groups own industry such as acacia wood, acacia bark and black liquor.

Another company, Growth Steel group, has developed a number of biomass power plants using palm oil solid waste as fuel feedstock in several locations in Indonesia:

- 2 x 15 MW in Medan, Sumatera Utara
- 1 x 15 MW in Simalungun Sumatera Utara
- 2 x 15 MW in Jambi
- 1 x 15 MW in Cilegon, Banten

Growth Steel group is a foundry industry based in Medan, Sumatera Utara. The company also sells excess power of 49 MW to PLN with the selling electricity price of 975 rupiahs per kWh.

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Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

The data sheet describes plants used for production of electricity. These data do not apply for industrial plants, which typically deliver heat at higher temperatures than power generation plants, and therefore they have lower electricity efficiencies. Also, industrial plants are often cheaper in initial investment and O&M, among others because they are designed for shorter technical lifetimes, with less redundancy, low-cost buildings etc.

Technology	Biomass power plant (smal plant - pumped oil and rice fields biomass waste)								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	25	25	25	1	50	1	50		1,5
Generating capacity for total power plant (MWe)	25	25	25	1	50	1	50		1,5
Electricity efficiency, net (%), name plate	32	32	32	25	35	25	35		1,3,7
Electricity efficiency, net (%), annual average	31	31	31	25	35	25	35		1,3,7
Forced outage (%)	7	7	7	5	9	5	9	A	1
Planned outage (weeks per year)	6	6	6	5	8	5	8	A	1
Technical lifetime (years)	25	25	25	19	31	19	31	A	8,10
Construction time (years)	2	2	2	2	3	2	3	A	10
Space requirement (1000 m^2/MWe)	35	35	35	26	44	26	44	A	1,9
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	10	10	10						3
Minimum load (% of full load)	30	30	30						3
Warm start-up time (hours)	0.5	0.5	0.5						3
Cold start-up time (hours)	10	10	10						3
Environment									
PM 2.5 (mg per Nm^3)	12.5	12.5	12.5						3
SO_2 (degree of desulphuring, %)	0.0	0.0	0.0						3
NO_X (g per GJ fuel)	125	125	125						3
CH_4 (g per GJ fuel)	0.9	0.9	0.9						3
N_2O (g per GJ fuel)	1.1	1.1	1.1						3
Financial data									
Nominal investment (M$/MWe)	1.7	1.6	1.4	1.3	2.2	1.0	1.7	B	4-8,11
- of which equipment	65	65	65	50	85	50	85		1,2
- of which installation	35	35	35	15	50	15	50		1,2
Fixed O&M ($/MWe/year)	47,600	43,800	38,100	35,700	59,500	28,600	47,600	A	4,5,8,11
Variable O&M ($/MWh)	3.0	2.8	2.4	2.3	3.8	1.8	3.0	A	5,11
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

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4 IRENA, 2015, "Renewable power generation cost in 2014"

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9 India Central Electricity Authority, 2007, "Report on the Land Requirement of Thermal Power Stations".

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11 Learning curve approach for the development of financial parameters.

Notes:

A Uncertainty (Upper/Lower) is estimated as +/- 25%.

B Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

7. MUNICIPAL SOLID WASTE AND LAND-FILL GAS POWER PLANTS

Brief technology description
Municipal solid waste (MSW) is a waste type consisting of everyday items that are discarded by the public. The composition of MSW varies greatly from municipality to municipality, and it changes significantly with time. The MSW industry has four components: recycling, composting, disposal, and waste-to-energy. MSW can be used to generate energy. Several technologies have been developed that make the processing of MSW for energy generation cleaner and more economically viable than ever before, including landfill gas capture, combustion, pyrolysis, gasification, and plasma arc gasification (ref. 1). While older waste incineration plants emitted a lot of pollutants, recent regulatory changes and new technologies have significantly reduced this concern. This chapter concentrates on incineration plants and landfill gas power plants.

Incineration power plants
The major components of waste to energy (WtE) incineration power plants are: a waste reception area, a feeding system, a grate fired furnace interconnected with a steam boiler, a steam turbine, a generator, an extensive flue gas cleaning system and systems for handling of combustion and flue gas treatment residues.

The method of using incineration to convert municipal solid waste to energy is a relatively old method of WtE production. Incineration generally entails burning waste (residual MSW, commercial, industrial, and refuse-derived fuel) to boil water which powers steam generators that make electric energy and heat to be used in homes, businesses, institutions and industries. One problem associated with incinerating MSW to make electrical energy is the potential for pollutants to enter the atmosphere with the flue gases from the boiler. These pollutants can be acidic and were in the 1980s reported to cause environmental damage by turning rain into acid rain. Since then, the industry has removed this problem by the use of lime scrubbers and electro-static precipitators on smokestacks. By passing the smoke through the basic lime scrubbers, any acids that might be in the smoke are neutralized, which prevents the acid from reaching the atmosphere and hurting the environment. Many other devices, such as fabric filters, reactors, and catalysts destroy or capture other regulated pollutants.

The caloric value of MSW depends on the composition of the waste. Next table gives the estimated caloric value of MSW components on dry weight basis.

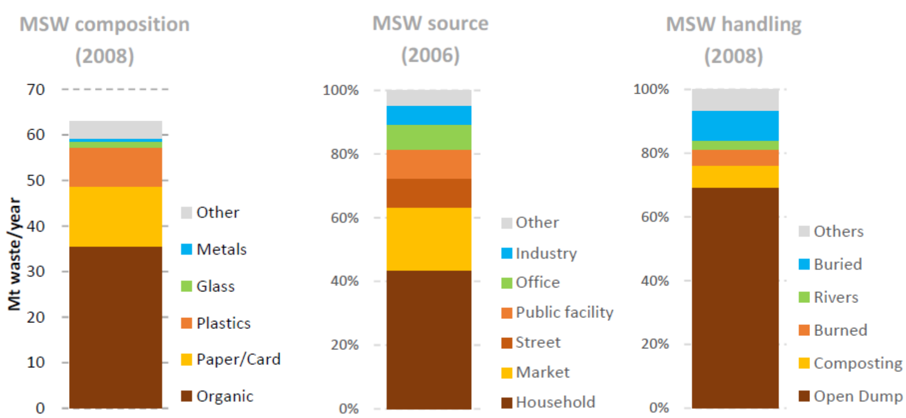
Average heat values of MSW components (ref. 2)

Component	**Heat Value (GJ/ton)**
Food Waste	4.7
Paper	16.8
Cardboard	16.3
Plastics	32.6
Textiles	17.5
Rubber	23.3
Leather	1.7
Garden trimmings	6.5
Wood	18.6
Glass	0.1
Metals	0.7

The waste is delivered by trucks and is normally incinerated in the state in which it arrives. Only bulky items are shredded before being fed into the waste bunker.

About 65 million tons of urban solid waste was produced in Indonesia in 2016 (ref. 3), which is straining the country's existing waste management infrastructure. More than two-thirds of this waste stream is disposed in the country's approximately 380 open landfill sites, several of which are approaching their maximum capacity. The remainder is predominantly buried, burned, composted or remains unmanaged.

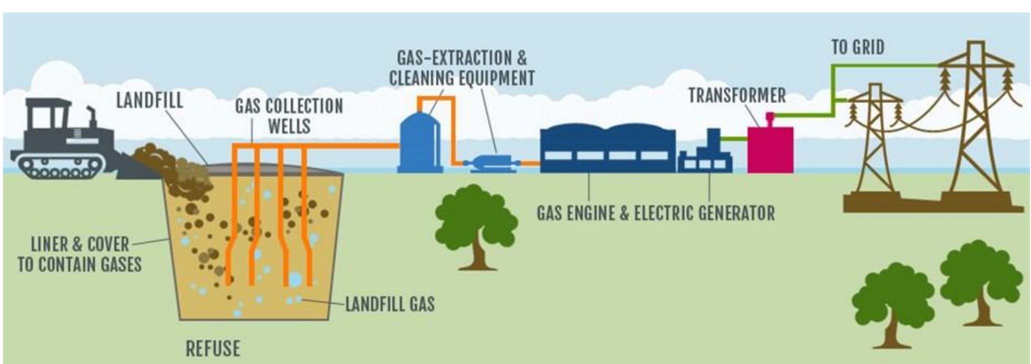
The figure below summarizes Indonesia's MSW composition, source and handling methods from left to right.



Indonesia's Municipal Solid Waste composition, source and handling statistics (ref. 4)

Landfill gas power plants

The disposal of wastes by land filling or land spreading is the current most common fate of solid waste. As solid waste in landfills decomposes, landfill gas is released. Landfill gas consists of approximately 50% methane, 42% carbon dioxide, 7% nitrogen and 1% oxygen compounds. Landfill gas is a readily available, local and renewable energy source that offsets the need for non-renewable resources such as oil, coal and gas. Using gas engines, land-fill gas can be used as fuel feedstock to produce electricity. The production volume of land-fill gas from the same sites can have a range of 2-16 m^3/day.



Land-fill gas to energy (ref. 5)

Based on a World Bank study from 2005, total land-fill gas (LGF) power plant potential in 17 big cities in Indonesia is 79 MW, due to the fact that the majority of the land-fills are open dumping systems. If the systems are proper designed then the potential of LFG could be higher.

Land-fill gas potential in big cities in Indonesia (ref. 6)

No	City	MSW Production (million tons/year)	CH4 Emission (million m3/year)	Electricity Capacity (MW)
1	Medan	0.7	27	5
2	Pakanbaru	0.3	11	2
3	Padang	0.4	16	3
4	Jambi	0.2	7	1
5	Palembang	0.6	23	5
6	Bandar Lampung	0.4	15	3
7	Jakarta	3.5	140	29
8	Bandung	0.8	32	7
9	Semarang	0.5	21	4
10	Yogyakarta	0.1	5	1
11	Surabaya	0.8	33	7
12	Denpasar	0.2	9	2
13	Pontianak	0.2	7	1
14	Banjarmasin	0.2	7	2
15	Samarinda	0.2	9	2
16	Balikpapan	0.2	6	1
17	Makasar	0.5	19	4
	Total	9.8	387	79

The table below summarizes the suitability of each technology to selected waste streams from Municipal, Agricultural and Industrial sources. The basic outputs of each technology are also given in terms of electricity, heat, biogas, digestate, syngas and other commercial solids.

Summary of waste to energy technologies' suitability per waste stream and potential output (ref. 4)

CONVERSION TECHNOLOGIES		Anaerobic digestion	Landfill gas recovery	Incineration	Gasification	Pyrolysis
WASTE STREAMS						
Municipal or industrial	Food waste	green	green	orange	orange	orange
	Garden and park waste	green	green	orange	red	red
	Dry recoverable waste	red	red	green	green	green
	Refuse Derived Fuel	red	red	green	green	green
	Inert	red	green	red	red	red
	Hazardous	red	red	orange	red	red
	Solid Recovered Fuel	red	red	green	green	green
Agricultural	Biomass	green	green	orange	orange	orange
	Animal waste	green	green	orange	orange	orange
	Dry recoverable waste	red	red	green	green	green
	Hazardous	red	red	orange	red	red
OUTPUTS						
Electricity		x	x	x	x	x
Heat		x	x	x	x	x
Biogas		x	x			
Digestate		x				
Syngas					x	x
Other commercial solids				x	x	x

Key: (green) Directly suitable (orange) Likely to require pre-treatment (red) Unsuitable

Input
MSW and other combustible wastes, water and chemicals for flue gas treatment, gasoil or natural gas for auxiliary burners (if installed), and in some cases biomass for starting and closing down.

Land-fill gas is the fuel feedstock for the land-fill gas power plants.

Output
For combustion systems, the outputs are electricity and if demand for it the heat as hot (> 110 ^oC) or warm (<110 ^oC) water, bottom ash (slag), residues from flue gas treatment, including fly ash. If the flue gas is treated by wet methods, there may also be an output of treated or untreated process wastewater (the untreated wastewater originates from the SO2-step, when gypsum is not produced).

For land-fill gas systems, the outputs are electricity and heat. The land-fill gas which has been cleaned (from sulphur and carbon dioxide contents) can be sold as commercial gas through natural gas pipeline networks.

Typical capacities
Medium: 10 – 50 MW.
Small: 1 – 10 MW.

Ramping configurations
The plants that using combustion technologies can be down regulated to about 50% of the nominal capacity, under which limit the boiler may not be capable of providing adequate steam quality and environmental performance. For emission control reasons and due to high initial investments, they should be operated as base load.

Land-fill gas to energy plants can also be ramped up or down depending on the availability of the land-fill gas in a storage.

Advantages/disadvantages
Advantages:

- Waste volumes are reduced by an estimated 80-95%.
- Reduction of other electricity generation.
- Reduction of waste going to landfills.
- Avoidance of disposal costs and landfill taxes.
- Use of by-products as fertilizers.
- Avoid or utilisation of methane emissions from landfills.
- Reduction in carbon emitted.
- Domestic production of energy.
- The ash produced can be used by the construction industry.
- Incineration also eliminates the problem of leachate that is produced by landfills.

Disadvantages:

- Incineration facilities are expensive to build, operate, and maintain. Therefor incineration plants are usually build for environmental benefits, instead of for power generation reasons.
- Smoke and ash emitted by the chimneys of incinerators include acid gases, nitrogen oxide, heavy metals, particulates, and dioxin, which is a carcinogen. Even with controls in place, some remaining dioxin still enters the atmosphere.
- Incineration ultimately encourages more waste production because incinerators require large volumes of waste to keep the fires burning, and local authorities may opt for incineration over recycling and waste reduction programs.

It has been estimated that recycling conserves 3-5 times more energy than waste-to-energy generates because the energy required to make products derived from recycled materials is significantly less than the energy used to produce them from virgin raw materials.

In developing countries like Indonesia, waste incineration is likely not as practical as in developed countries, since a high proportion of waste in developing countries is composed of kitchen scraps. Such organic waste is composed of higher moisture content (40-70%) than waste in industrialized countries (20-40%), making it more difficult to burn.

Environment

The incineration process produces two types of ash. Bottom ash comes from the furnace and is mixed with slag, while fly ash comes from the stack and contains components that are more hazardous. In municipal waste incinerators, bottom ash is approximately 10% by volume and approximately 20 to 35% by weight of the solid waste input. Fly ash quantities are much lower, generally only a few percent of input. Emissions from incinerators can include heavy metals, dioxins and furans, which may be present in the waste gases, water or ash. Plastic and metals are the major source of the calorific value of the waste. The combustion of plastics, like polyvinyl chloride (PVC) gives rise to these highly toxic pollutants.

Leachate generation is a major problem for municipal solid waste (MSW) landfills and causes significant threats to surface water and groundwater. Leachate may also contain heavy metals and high ammonia concentration that may be inhibitory to the biological processes. Technologies for landfill leachate treatment include biological treatment, physical/chemical treatment and “emerging” technologies such as reverse osmosis (RO) and evaporation.

Leachate collection and treatment pond at Bantar Gebang Landfill gas power plant. (ref. 8)

Research and development

Waste incineration plants is a very mature technology (category 4), whereas landfill gas is commercialised, but still being gradually improved (category 3). There are, however, a number of other new and emerging technologies that are able to produce energy from waste and other fuels without direct combustion. Many of these technologies have the potential to produce more electric power from the same amount of fuel than would be possible by direct combustion. This is mainly due to the separation of corrosive components (ash) from the converted fuel, thereby allowing higher combustion temperatures in e.g. boilers, gas turbines, internal combustion engines, fuel cells. Some are able to efficiently convert the energy into liquid or gaseous fuels:

- *Pyrolysis* — MSW is heated in the absence of oxygen at temperatures ranging from 550 to 1300 degrees Fahrenheit. This releases a gaseous mixture called syngas and a liquid output, both of which can be used for electricity, heat, or fuel production. The process also creates a relatively small amount of charcoal. (ref. 1)
- *Gasification* — MSW is heated in a chamber with a small amount of oxygen present at temperatures ranging from 750 to 3000 degrees Fahrenheit. This creates syngas, which can be burned for heat or

power generation, upgraded for use in a gas turbine, or used as a chemical feedstock suitable for conversion into renewable fuels or other bio-based products. (ref. 1)

- *Plasma Arc Gasification* — Superheated plasma technology is used to gasify MSW at temperatures of 10,000 degrees Fahrenheit or higher - an environment comparable to the surface of the sun. The resulting process incinerates nearly all of the solid waste while producing from two to ten times the energy of conventional combustion. (ref. 1)

Efficiency of Energy Conversion Technologies (ref. 9 and ref. 10)

Technology	Efficiency (kWh/ton of waste)
Land-fill gas	41 – 84
Combustion (Incinerator)	470 – 930
Pyrolysis	450 – 530
Gasification	400 – 650
Plasma arc gasification	400 – 1250

Expected Landfill Diversion (ref. 11 and ref. 12)

Technology	Land diversion (% weight)
Land-fill gas	0
Combustion (Incinerator)	75*
Pyrolysis	72 – 95
Gasification	94 – 100
Plasma arc gasification	95 – 100

* 90% by volume

Examples of current projects

Up until now, Indonesia have not had waste to energy(WtE) plants using combustion technology. There are two land-fill gas power plants in operation currently in Indonesia, one at Bantar Gebang, near Jakarta, with installed capacity of 14.4 MW, the other one at Benowo, Surabaya, with installed capacity of 1.65 MW. Both locations are using sanitary landfill technologies and gas engines to produce electricity. There were several plans of landfill gas projects within the CDM scheme, but unfortunately all projects were postponed since the CDM schemes that were proposed remained unclear.

Land-fill gas power plant at Bantar Gebang, Bekasi, West Jawa (ref. 13)

References

The following sources are used:

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2. Reinhart, 2004. Estimation of Energy Content of Municipal Solid Waste, University of Central Florida, USA.
3. Viva Media Baru. http://www.viva.co.id. Accessed: 1st August 2017.
4. Rawlins et. al., 2014. *Waste to energy in Indonesia*, The Carbon Trust, London, United Kingdom.
5. Advanced Disposal Services. http://www.advanceddisposal.com. Accessed: 1st August 2017.
6. Morton, 2005. ”World Bank Experiencein Landfill Gas and Prospects for Indonesia”, *USEPA LMOP Conference*, Baltimore, USA.
7. Kardono, et. al., 2007. ”Landfill Gas for Energy: Its Status and Prospect in Indonesia”, *Proceeding of International Symposium on EcoTopia Science 2007*, ISETS07.
8. http://adriarani.blogspot.co.id/2011/12/bukan-tpa-bantar-gebang.html. Accessed: 12th August 2017.
9. Alternative Resources, Inc., 2008. “Evaluating Conversion Technology for Municipal Solid Waste Management.” Alternative Resources, Inc.
10. Department for Environment, Food, and Rural Affairs, 2004. “Review of Environmental and Health Effects of Waste Management: Municipal Solid Waste and Similar Wastes.” Department for Environment, Food, and Rural Affairs.
11. Alternative Resources, Inc., 2008. “Evaluating Conversion Technology for Municipal Solid Waste Management.” Alternative Resources, Inc.
12. Texas Comptroller of Public Accounts, 2008. “The Energy Report 2008: Chapter 18 Municipal Solid Waste Combustion.” Texas Comptroller of Public Accounts.
13. PT Godang Tua Jaya, Jakarta, Indonesia 2017.

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Incineration Power Plant - Municipal Solid Waste								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	22	22	23						
Generating capacity for total power plant (MWe)	22	22	23						
Electricity efficiency, net (%), name plate	29%	30%	31%	28%	32%	30%	33%	A	1
Electricity efficiency, net (%), annual average	28%	29%	29%	26%	30%	28%	31%		1
Forced outage (%)	1%	1%	1%						1
Planned outage (weeks per year)	2.9	2.6	2.1						1
Technical lifetime (years)	25	25	25						1
Construction time (years)	2.5	2.5	2.5						1
Space requirement (1000 m^2/MWe)	1.5	1.5	1.5						1
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	10	10	10	7.5	12.5	7.5	12.5	C	1
Minimum load (% of full load)	20	20	20	15.0	25.0	15.0	25.0	C	1
Warm start-up time (hours)	0.5	0.5	0.5	0.4	0.6	0.4	0.6	C	1
Cold start-up time (hours)	2	2	2	1.5	2.5	1.5	2.5	C	1
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	8.7	8.1	7.2	6.5	9.0	5.4	9.0	C	1
- of which equipment	5.2	4.4	3.6	3.9	4.5	2.7	4.5		1
- of which installation	3.6	3.7	3.6	2.7	4.5	2.7	4.5		1
Fixed O&M ($/MWe/year)	243,700	224,800	193,500	195,000	304,600	154,800	241,900	C	1
Variable O&M ($/MWh)	24.1	23.4	22.6	18.1	28.2	16.9	28.2	C	1
Start-up costs ($/MWe/start-up)									
Technology specific data									
Waste treatment capacity (tonnes/h)	27.7	27.7	27.7					B	

References:

1 Danish Technology Catalogue "Technology Data for Energy Plants, Danish Energy Agency 2107- update in progress

Notes:

A Based on experience from the Netherlands where 30 % electric efficiency is achieve. 1 %-point efficiency subtracted to take into account higher temperature of cooling water in Indonesia (approx. +20 C).

B The investment cost is based on waste to energy CHP plant in Denmark, according to Ref 1. A waste treatment capacity of 27,7 tonnes/h is assumed and an energy content of 10,4 GJ/ton. The specific finalcial data is adjusted to reflect that the plant in Indonesia runs in condensing mode and hence the electric capacity (MWe) is higher than for a combined heat and power, backpressure plant with the same treatment capacity.

C Uncertainty (Upper/Lower) is estimated as +/- 25%.

D Calculated from size, fuel efficiency and an average calory value for waste of 9.7 GJ/ton.

Technology	Landfill Gas Power Plant - Municipal Solid Waste								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	1	1	1	0.5	10	0.5	10		1
Generating capacity for total power plant (MWe)	1	1	1	0.5	10	0.5	10		1
Electricity efficiency, net (%), name plate	35	35	35	25	37	25	37		2
Electricity efficiency, net (%), annual average	34	34	34	25	37	25	37		2
Forced outage (%)	5	5	5	2	15	2	15		4
Planned outage (weeks per year)	5	5	5	2	15	2	15		4
Technical lifetime (years)	25	25	25	20	30	20	30		3
Construction time (years)	1.5	1.5	1.5	1	3	1	3		3
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	2.5	2.5	2.5	2.3	2.8	2.3	2.9	A	3
- of which equipment	0.7	0.7	0.7	0.7	0.8	0.7	0.8		5
- of which installation	0.3	0.3	0.3	0.3	0.3	0.3	0.3		5
Fixed O&M ($/MWe/year)	125,000	125,000	125,000	113,640.0	137,500.0	113,636.4	143,750.0	A	3
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1 OJK, 2014, "Clean Energy Handbook for Financial Service Institutions", Indonesia Financial Service Authority, Jakarta, Indonesia

2 Renewables Academy" (RENAC) AG, 2014, "Biogas Technology and Biomass", Berlin, Germany.

3 IEA-ETSAP and IRENA, 2015. "Biomass for Heat and Power, Technology Brief".

4 PLN, 2017, data provided the System Planning Division at PLN

5 MEMR, 2015, "Waste to Energy Guidebook", Jakarta, Indonesia.

Notes:

A Uncertainty (Upper/Lower) is estimated as +/- 25%.

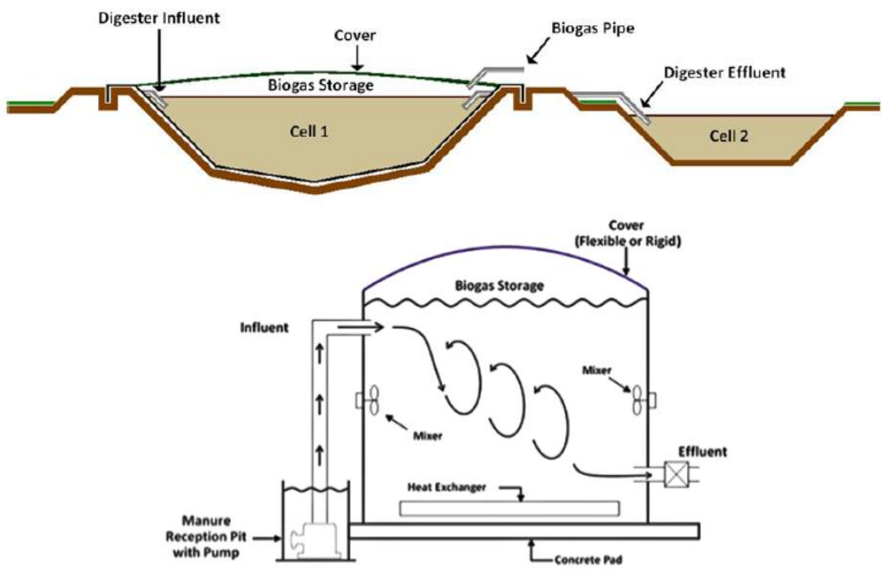
8. BIOGAS POWER PLANT

Brief technology description
Biogas produced by anaerobic digestion is a mixture of several gases. The most important part of the biogas is methane. Biogas has a caloric value between 23.3 – 35.9 MJ/m3, depending on the methane content. The percentage of volume of methane in biogas varies between 50 to 72% depending on the type of substrate and its digestible substances, such as carbohydrates, fats and proteins. If the material consists of mainly carbohydrates, the methane production is low. However, if the fat content is high, the methane production is likewise high. For the operation of power generation or CHP units with biogas, a minimum concentration of methane of 40 to 45% is needed. The second main component of biogas is carbon dioxide. Its composition in biogas reaches between 25 and 50% of volume. Other gases present in biogas are hydrogen sulphide, nitrogen, hydrogen and steam (ref. 1 and ref. 2).

Feedstocks of biogas production in Indonesia are mainly from animal manure, agricultural waste including agriculture industries like palm oil mill effluent (POME), municipal solid waste (MSW) and land-fill. Some of the biomass potential can be converted to biogas. MSW and land-fill biogas will be discussed in chapter 7. It is estimated that the biogas potential from POME in Indonesia is about 430 MWe in 2015 (ref. 3)

Anaerobic digestion (AD) is a complex microbiological process in the absence of oxygen used to convert the organic matter of a substrate into biogas. The population of bacteria which is able to produce methane cannot survive with the presence of oxygen. The microbiological process of AD is very sensitive to changes in environmental conditions, like temperature, acidity, level of nutrients, etc. The temperature range that would give better cost-efficiency for operation of biogas power plants are around 35 – 38ºC (mesophilic) or 55 – 58ºC (thermophilic). Mesophilic gives hydraulic retention time (HRT) between 25 – 35 days and thermophilic 15 – 25 days (ref. 2).

There are different types and sizes of biogas systems: household biogas digesters, covered lagoon biogas systems and Continuously Stirred Tank Reactor (CSTR) or industrial biogas plants. The last two systems have been largely applied to produce heat and/or electricity (CHP) commercially for own use and sale to customers.



Covered lagoon and CSTR biogas plants (ref.3)

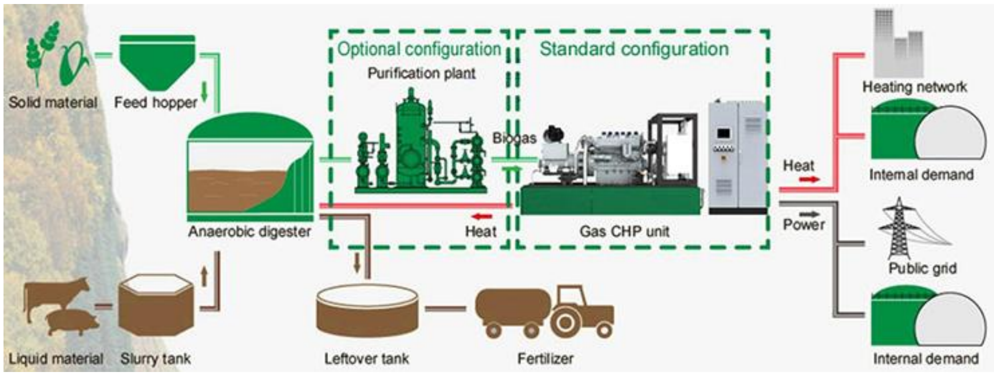
Covered lagoon systems are applied for which the biogas feedstocks are mostly liquid waste like POME. POME is stored in a lake that is covered by an airtight membrane to capture biogas during anaerobic biological conversion processes. In CSTR systems, liquid waste is stored in tanks to capture biogas during the anaerobic biological conversion process. In general, this type of technology has several stirrers in the tank that serves to stir the material that has higher solids content (≥12%) continuously.

The output of biogas depends much on the amount and quality of supplied organic waste. For manure the gas output is typically 14 – 14.5 m3 methane per tonne, while the gas output typically is 30 – 130 m3 methane per tonne for industrial waste (ref. 4). Additional biogas storage is required when the consumption of biogas is not continuous. Biogas storage would be beneficial to accommodate when demand is higher or lower than the biogas production.

The potential electricity that can be generated from Palm Oil Mill Effluent (POME) (from EBTKE)

Parameters	Value	Unit
Fresh Fruit Bunch (FFB)	1,000,000	ton/year
POME yield	650,000	m3
Biogas yield from POME	25	m3-biogas/m3-POME
Methane (CH4) fraction in biogas	0.625	m3-methane/m3-biogas
Methane emitted	10,156,250	m3
Electricity production (38% efficiency)	38.6	GWh
Capacity (100% availability)	4.4	MW

Biogas from a biodigester is transported to the gas cleaning system to remove sulphur and moisture before entering the gas engine to produce electricity. The excess heat from power generation with internal combustion engines can be used for space heating, water heating, process steam covering industrial steam loads, product drying, or for nearly any other thermal energy need. The efficiency of a biogas power plant is about 35% if it is just used for electricity production. The efficiency can go up to 80% if the plant is operated as combined heat and power (CHP).



Biogas CHP working diagram (ref. 5)

Input

Bio-degradable organic waste without environmentally harmful components such as, animal manure, solid and liquid organic waste from industry. Sludge from sewage treatment plants and the organic fraction of household waste may also be used.

Output
Electricity and heat.
The data presented in this technology sheet assume that the biogas is used as fuel in an engine, which produces electricity and heat, or sold to a third party. However, the gas may also be injected into the natural gas grid or used as fuel for vehicles. The digested biomass can be used as fertilizer in crop production.

Typical capacities
Medium: 10 – 50 MW.
Small: 1 – 10 MW.

Ramping configurations
Similar to gas power plants, biogas power plants can ramp up and down. However, there is a biological limit to how fast the production of biogas can change. This is not the case for the plants which have biogas storage. Biogas storage would be beneficial to accommodate when demand is higher or lower than the biogas production.

Advantages/disadvantages
The CO_2 abatement cost is quite low, since methane emission is mitigated.

- Saved expenses in manure handling and storage; provided separation is included and externalities are monetized.
- Environmentally critical nutrients, primarily nitrogen and phosphorus, can be redistributed from overloaded farmlands to other areas.
- The fertilizer value of the digested biomass is better than the raw materials. The fertilizer value is also better known, and it is therefore easier to distribute the right amount on the farmlands.
- Compared with other forms of waste handling, biogas digestion of solid biomass has the advantage of recycling nutrients to the farmland – in an economically and environmentally sound way.

Environment
Biogas is a CO_2-neutral fuel. Also, without biogas fermentation, significant amounts of the greenhouse gas methane will be emitted to the atmosphere. For biogas plants in Denmark the CO_2 mitigation cost has been determined to approx. 5 € per tonne CO_2-equivalent (ref. 6).

The anaerobic treated organic waste product is almost free compared to raw organic waste.

Research and development
Stirling engines create opportunities to produce electricity (and also heat) using biogas of any type and quality (category 3). A Stirling engine is a heat engine that operates by cyclic compression and expansion of air or other gases (the working fluid) at different temperatures, such that there is a net conversion of heat energy to mechanical work (ref. 7). More specifically, the Stirling engine is a closed-cycle regenerative heat engine with a permanently gaseous working fluid.

Stirling engines have a high efficiency compared to steam engines, being able to reach 50% efficiency. They are also capable of quiet operation and can use almost any heat source. The heat energy source is generated externally to the Stirling engine rather than by internal combustion as with Otto cycle or Diesel cycle engines. Because the Stirling engine is compatible with alternative and renewable energy sources it could become increasingly significant as the price of conventional fuels rises, and also in light of concerns such as depletion of oil supplies and climate change.

The current Stirling combined heat and power system (ref. 8) can produce both electricity and heat from a methane gas concentration as low as 18% – with multiple applications from biogas and landfill sites to waste water treatment.

Makel Engineering, Inc. (MEI), Sacramento Municipal Utility District, and the University of California, Berkeley developed a homogenous charge compression ignition (HCCI) engine-generator (genset) that efficiently produces electricity from biogas. The design of the HCCI engine-generator set, or “genset,” is based on a combination of spark ignition and compression ignition engine concepts, which enables the use of fuels with very low energy content (such as biogas from digesters) to achieve high thermal efficiency while producing low emissions. Field demonstrations at a dairy south of Sacramento, California show that this low-cost, low-emission energy conversion system can produce up to 100 kilowatts (kW) of electricity while maintaining emission levels that meet the California Air Resources Board’s (ARB) strict regulations (ref. 9).

Examples of market standards

The development of biogas power plants in Indonesia is still limited to small capacities, less than 10 MWe. There are two palm oil plantation companies in East Kalimantan which have built biogas power plants. One is PT REA Kaltim Plantations. This company built a 7 MW biogas power plant using palm oil mill effluent (POME) as fuel feedstock. The other company is PT Prima Mitrajaya Mandiri. This company owns a 4 MW biogas power plant also using POME as fuel feedstock.

Covered lagoon type – biogas power plant of PT REA Kaltim Plantations (ref. 10)

The largest biogas power plant in the world is located in Finland. It has an installed capacity of 140 MW. Fueled mainly with wood residue from Finland's large forestry sector, the plant is expected to reduce carbon-dioxide emissions by 230,000 tons per year while providing both heating and electricity for Vaasa's approximately 61,000 residents. (ref. 11)

References

The following sources are used:

1. Jorgensen, 2009. *Biogas – green energy*, Faculty of Agricultural Sciences, Aarhus University, 2nd edition, Denmark
2. RENAC. *Biogas Technology and Biomass*, Renewables Academy (RENAC) AG, Berlin, Germany.
3. IIEE, 2015. ”User guide for Bioenergy Sector”, *Indonesia 2050 Pathway Calculator*, Jakarta, Indonesia.

4. DEA, 2015. *Technology Data for Energy Plants*, Danish Energy Agency, Copenhagen, Denmark
5. Ettes Power Machinery, http://www.ettespower.com/Methane-Gas-Generator.html, Accessed: 10th August 2017.
6. Ministry of Environment, 2003. *Danish Climate Strategy*, Denmark.
7. Walker, 1980. "Stirling Engines", *Clarenden Press*, Oxford, London, England.
8. Cleanenergy, 2014. Stirling CHP Systems: Driving the future of biogas power, Cleanenergy AB, Sweden
9. Makel Engineering, 2014. "Biogas-Fuelled Hcci Power Generation System For Distributed Generation", *Energy Research and Development Division*, *Final Project Report*, California, USA.
10. PT REA Kaltim Plantations, http://reakaltim.blogspot.co.id. Accessed" 10th August 2017.
11. Industry Week. http://www.industryweek.com/energy/worlds-largest-biogas-plant-inaugurated-finland. Accessed 1st August 2017.

Data sheets

The follow pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Biogas power plant								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	1	1	1						3
Generating capacity for total power plant (MWe)	1	1	1						3
Electricity efficiency, net (%), name plate	35	35	35						4
Electricity efficiency, net (%), annual average	34	34	34						4
Forced outage (%)	5	5	5						1
Planned outage (weeks per year)	5	5	5						1
Technical lifetime (years)	25	25	25						7
Construction time (years)	1.5	1.5	1.5						7
Space requirement (1000 m^2/MWe)	70	70	70						12
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	20	20	20	10	30	10	30		11
Minimum load (% of full load)	20	30	15	30	50	10	40		10
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (mg per Nm^3)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	2.8	2.6	2.2	2.1	3.5	1.7	2.8	A	3,5,8,9
- of which equipment	65	65	65	50	85	50	85		
- of which installation	35	35	35	15	50	15	50		
Fixed O&M ($/MWe/year)	97,000	89,200	77,600	72,800	121,300	58,200	97,000	A	5,7,9
Variable O&M ($/MWh)	0.11	0.1	0.1	0.1	0.1	0.1	0.1	A	6,9
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 ASEAN Centre of Energy (2016). Levelised cost of electricity generation of selected renewable energy technologies in the ASEAN member states.

3 Winrock, 2015, "Buku Panduan Konversi POME Menjadi Biogas, Pengembangan Proyek di Indonesia", USAID – Winrock International.

4 RENAC, 2014, "Biogas Technology and Biomass, Renewables Academy (RENAC)".

5 IFC and BMF, 2017, Converting biomass to energy - A guide for developmers and investors".

6 OJK, 2014, "Clean Energy Handbook for Financial Service Institutions", Indonesia Financial Service Authority.

7 IEA-ETSAP and IRENA, 2015, "Biomass for Heat and Power, Technology Brief".

8 PKPPIM, 2014, "Analisis biaya dan manfaat pembiayaan investasi limbah menjadi energi melalui kredit program", Center for Climate Change and Multilateral Policy Ministry of Finance Indonesia.

9 Learning curve approach for the development of financial parameters.

10 Vuorinen, A., 2008, "Planning of Optimal Power Systems".

11 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.

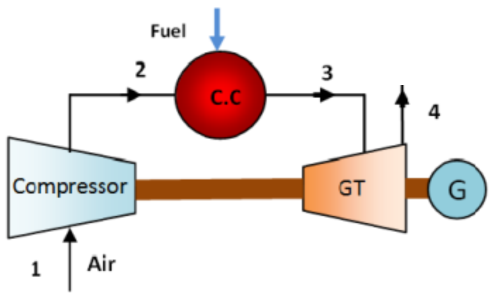
12 Chazaro Gerbang Internasional, 2004, "Utilization of Biogas Generated from the Anaerobic Treatment of Palm Oil Mills Effluent (POME) as Indigenous Energy Source for Rural Energy Supply and Electrification - A Pre-Feasibility Study Report"

Notes:

A Uncertainty (Upper/Lower) is estimated as +/- 25%.

9. GAS TURBINE – SIMPLE CYCLE

Brief technology description
The major components of a simple-cycle (or open-cycle) gas turbine power unit are: a gas turbine, a gear (when needed) and a generator.



Process diagram of a CCGT (ref. 1)

There are in general two types of gas turbines;
1. industrial turbines (also called heavy duty)
2. aero-derivative turbine

Industrial gas turbines differ from aero-derivative turbines in the way that the frames, bearings and blading are of heavier construction. Additionally, industrial gas turbines have longer intervals between services compared to the aero-derivatives.

Aero-derivative turbines benefit from higher efficiency than industrial ones and the most service-demanding module of the aero-derivative gas turbine can normally be replaced in a couple of days, thus keeping a high availability.

Gas turbines can be equipped with compressor intercoolers where the compressed air is cooled to reduce the power needed for compression. The use of integrated recuperators (preheating of the combustion air) to increase efficiency can also be made by using air/air heat exchangers - at the expense of an increased exhaust pressure loss. Gas turbine plants can have direct steam injection in the burner to increase power output through expansion in the turbine section (Cheng Cycle).

Small (radial) gas turbines below 100 kW are now on the market, the so-called micro-turbines. These are often equipped with preheating of combustion air based on heat from gas turbine exhaust (integrated recuperator) to achieve reasonable electrical efficiency (25-30%).

Input
Typical fuels are natural gas and light oil. Some gas turbines can be fuelled with other fuels, such as LPG, biogas etc., and some gas turbines are available in dual-fuel versions (gas/oil).

Gas fired gas turbines need an input pressure of the fuel (gas) of 20-60 bar, dependent on the gas turbine compression ratio, i.e. the entry pressure in the combustion chamber. Typically, aero derivative gas turbines need higher fuel (gas) pressure than industrial types.

Output
Power.

Typical capacities
Simple-cycle gas turbines are available in the 30 kW – 450 MW range.

Ramping configurations
A simple-cycle gas turbine can be started and stopped within minutes, supplying power during peak demand. Because they are less power efficient than combined cycle plants, they are in most places used as peak or reserve power plants, which operate anywhere from several hours per day to a few dozen hours per year.

However, every start/stop has a measurable influence on service costs and maintenance intervals. As a rule-of-thumb, a start costs 10 hours in technical life expectancy.

Gas turbines are able to operate at part load. This reduces the electrical efficiency and at lower loads the emission of e.g. NOx and CO will increase. The increase in NOx emissions with decreasing load places a regulatory limitation on the ramping ability. This can be solved in part by adding de-NOx units.

Advantages/disadvantages
Advantages:
Simple-cycle gas turbine plants have short start-up/shut-down time, if needed. For normal operation, a hot start will take some 10-15 minutes. Construction times for gas turbine based simple cycle plants are shorter than steam turbine plants.

Disadvantages:
Concerning larger units above 15 MW, the combined cycle technology has so far been more attractive than simple cycle gas turbines, when applied in cogeneration plants for district heating. Steam from other sources (e.g. waste fired boilers) can be led to the steam turbine part as well. Hence, the lack of a steam turbine can be considered a disadvantage for large-scale simple cycle gas turbines.

Environment
Gas turbines have continuous combustion with non-cooled walls. This means a very complete combustion and low levels of emissions (other than NOx). Developments focusing on the combustors have led to low NOx levels. To lower the emission of NOx further, post-treatment of the exhaust gas can be applied, e.g. with SCR catalyst systems.

Employment
The 1605 MW natural gas fired power plant Muara Karang near Jakarta (1205 MW CCGT + 400 MW steam turbine) is occupying 437 full time employees.

Research and development perspectives
Gas turbines are a very well-known and mature technology – i.e. category 4.

Increased efficiency for simple-cycle gas turbine configurations has also been reached through inter-cooling and recuperators. Research into humidification (water injection) of intake air processes (HAT) is expected to lead to increased efficiency due to higher mass flow through the turbine.

Additionally, continuous development for less polluting combustion is taking place. Low-NOx combustion technology is assumed. Water or steam injection in the burner section may reduce the NOx emission, but also the total efficiency and thereby possibly the financial viability. The trend is more towards dry low-NOx combustion, which increases the specific cost of the gas turbine.

References

The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following are sources are used:

1. Nag, "Power plant engineering", 2009.

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Simple Cycle Gas Turbine - large system								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	50	50	50	35	65	35	65		3
Generating capacity for total power plant (MWe)	100	100	100	35	150	35	150		3
Electricity efficiency, net (%), name plate	34	36	40						1,2
Electricity efficiency, net (%), annual average	33	35	39						1,2
Forced outage (%)	2	2	2						
Planned outage (weeks per year)	3	3	3						
Technical lifetime (years)	25	25	25						
Construction time (years)	1.5	1.5	1.5	1.1	1.9	1.1	1.9	B	3
Space requirement (1000 m^2/MWe)	0.02	0.02	0.02	0.015	0.025	0.015	0.025	B	3
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	20	20	20	10	30	10	30	C	3,8
Minimum load (% of full load)	20	30	15	30	50	10	40	A	6
Warm start-up time (hours)	0.25	0.23	0.20						3
Cold start-up time (hours)	0.5	0.5	0.5						3
Environment									
PM 2.5 (mg per Nm^3)	30	30	30	30	30	30	30		7
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-	E	
NO_X (g per GJ fuel)	86	60	20	20	86	20	86	A,D	3,7
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	0.77	0.73	0.68	0.65	1.20	0.55	0.80	F,G	1-5
- of which equipment	50	50	50	50	50	50	50		9
- of which installation	50	50	50	50	50	50	50		9
Fixed O&M ($/MWe/year)	23,200	22,500	21,800	17,400	29,000	16,400	27,300	B	1-5
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)	24	24	24	18	30	18	30	B	6

References:

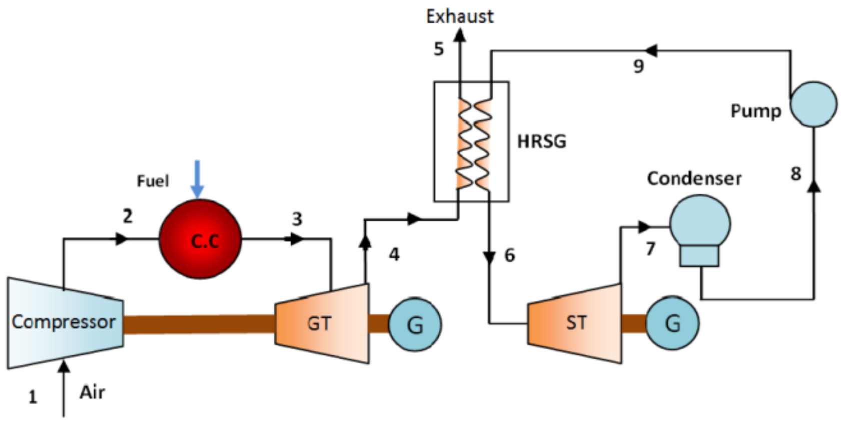
1 IEA, Projected Costs of Generating Electricity, 2015.
2 IEA, World Energy Outlook, 2015.
3 Danish Energy Agency, 2015, "Technology Catalogue on Power and Heat Generation".
4 Learning curve approach for the development of financial parameters.
5 Energy and Environmental Economics, 2014, "Capital Cost Review of Power Generation Technologies - Recommendations for WECC's 10- and 20-Year Studies".
6 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.
7 Maximum emission from Minister of Environment Regulation 21/2008
8 Vuorinen, A., 2008, "Planning of Optimal Power Systems".

Notes:

A Assumed gradidual improvement to international standard in 2050.
B Uncertainty (Upper/Lower) is estimated as +/- 25%.
C Assumed no improvement for regulatory capability.
D Calculated from a max of 400 mg/Nm3 to g/GJ (conversion factor 0.27 from Pollution Prevention and Abatement Handbook, 1998)
E Commercialised natural gas is practically sulphur free and produces virtually no sulphur dioxide
F The investment cost of an aero-derivative gas turbine will be in the higher end than an industrial gas turbine (ref. 5) . Roughly 50% higher.
G Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

10. GAS TURBINE – COMBINED CYCLE

Brief technology description
Main components of combined-cycle gas turbine (CCGT) plants include: a gas turbine, a steam turbine, a gear (if needed), a generator, and a heat recovery steam generator (HRSG)/flue gas heat exchanger, see the diagram below.



Process diagram of a CCGT (ref. 1)

The gas turbine and the steam turbine are shown driving a shared generator. The gas turbine and the steam turbine might drive separate generators (as shown) or drive a shared generator. Where the single-shaft configuration (shared) contributes with higher reliability, the multi-shaft (separate) has a slightly better overall performance. The condenser is cooled by sea water or a water circulating in a cooling tower.

The electric efficiency depends, besides the technical characteristics and the ambient conditions, on the flue gas temperature and the temperature of the cooling water. The power generated by the gas turbine is typically two to three times the power generated by the steam turbine.

Input
Typical fuels are natural gas and/or light oil. Some gas turbines can be fueled with other fuels, such as LPG, biogas etc., and some gas turbines are available in dual-fuel versions (gas/oil).

Gas fired gas turbines need a fuel gas pressure of 20-60 bar.

Output
Power.

Typical capacities
Most CCGT units has an electric power of >40 MW. The enclosed datasheets cover large scale CCGT (100 – 400 MW) and medium scale (10 – 100 MW).

Ramping configurations
CCGT units are to some extent able to operate at part load. This will reduce the electrical efficiency and often increase the NOx emission.

If the steam turbine is not running, the gas turbine can still be operated by directing the hot flue gasses through a boiler designed for high temperature or into a bypass stack.

The larger gas turbines for CCGT installations are usually equipped with variable inlet guide vanes, which will improve the part-load efficiencies in the 85-100% load range, thus making the part-load efficiencies comparable with conventional steam power plants in this load range. Another means to improve part-load efficiencies is to split the total generation capacity into several CCGTs. However, this will generally lead to a lower full load efficiency compared to one larger unit.

Advantages/disadvantages
Large gas turbine based combined-cycle units are world leading with regard to electricity production efficiency among fuel based power production.

Smaller CCGT units have lower electrical efficiencies compared to larger units. Units below 20 MW are few and will face close competition with single-cycle gas turbines and reciprocating engines.

Gas fired CCGTs are characterized by low capital costs, high electricity efficiencies, short construction times and short start-up times. The economies of scale are however substantial, i.e. the specific cost of plants below 200 MW increases as capacity decreases.

The high air/fuel ratio for gas turbines leads to lower overall efficiency for a given flue gas cooling temperature compared to steam cycles and cogeneration based on internal combustion engines.

Research and development
Gas turbines are a very well-known and mature technology – i.e. category 4.

Continuous research is done concerning higher inlet temperature at first turbine blades to achieve higher electricity efficiency. This research is focused on materials and/or cooling of blades.

Continuous development for less polluting combustion is taking place. Increasing the turbine inlet temperature may increase the NOx production. To keep a low NOx emission different options are at hand or are being developed, i.e. dry low-NOx burners, catalytic burners etc.

Development to achieve shorter time for service is also being done.

Examples of current projects

- Muara Tawar Block 5, near Jakarta – CCGT 235 MW. Commissioned in 2010.

References
The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following are sources are used:

1. Ibrahim & Rahman, "Effect of Compression Ratio on Performance of Combined Cycle Gas Turbine", *Int. J. Energy Engineering*, 2012.
2. Nag, "Power plant engineering", 2009.
3. Mott MacDonald, "UK Electricity Generation Costs Update", 2010.

Data sheets

The following pages content the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* it related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Combined Cycle Gas Turbine								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	600	600	600	200	800	200	800		1
Generating capacity for total power plant (MWe)	600	600	600	200	800	200	800		1
Electricity efficiency, net (%), name plate	57	60	61	45	62	55	65		1,3,5,10
Electricity efficiency, net (%), annual average	56	59	60	39	61	54	64		
Forced outage (%)	5	5	5	3	10	3	10		1
Planned outage (weeks per year)	5	5	5	3	8	3	8		1
Technical lifetime (years)	25	25	25	20	30	20	30		1
Construction time (years)	2.5	2.5	2.5	2	3	2	3		1
Space requirement (1000 m^2/MWe)	-	-	-	-	-	-	-		
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	20	20	20	10	30	10	30	C	1,2
Minimum load (% of full load)	45	30	15	30	50	10	40	A	5
Warm start-up time (hours)	2	1	1	1	3	0.5	2	A	1,5
Cold start-up time (hours)	4	4	4	2	5	2	5		1,5
Environment									
PM 2.5 (mg per Nm^3)	30	30	30						
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-	E	
NO_X (g per GJ fuel)	86	60	20	20	86	20	86	A,D	7,8
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	0.75	0.71	0.66	0.65	0.80	0.55	0.70	F	1,3,10
- of which equipment	50	50	50	50	50	50	50		9
- of which installation	50	50	50	50	50	50	50		9
Fixed O&M ($/MWe/year)	23,200	22,500	21,800	17,400	29,000	16,400	27,300	B	1,3
Variable O&M ($/MWh)	0.13	0.13	0.12	0.10	0.16	0.09	0.15	B	1
Start-up costs ($/MWe/start-up)	80	80	80	60	100	60	100	B	6

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Vuorinen, A., 2008, "Planning of Optimal Power Systems".

3 IEA, World Energy Outlook, 2015.

4 Learning curve approach for the development of financial parameters.

5 Siemens, 2010, "Flexible future for combined cycle".

6 Deutsches Institut für Wirtschaftsforschung, On Start-up Costs of Thermal Power Plants in Markets with Increasing Shares of Fluctuating Renewables, 2016.

7 Maximum emission from Minister of Environment Regulation 21/2008

8 Danish Energy Agency, 2015, "Technology Catalogue on Power and Heat Generation".

9 Soares, 2008, "Gas Turbines: A Handbook of Air, Land and Sea Applications".

10 IEA, Projected Costs of Generating Electricity, 2015.

Notes:

A Assumed gradidual improvement to international standard in 2050.

B Uncertainty (Upper/Lower) is estimated as +/- 25%.

C Assumed no improvement for regulatory capability.

D Calculated from a max of 400 mg/Nm3 to g/GJ (conversion factor 0.27 from Pollution Prevention and Abatement Handbook, 1998)

E Commercialised natural gas is practically sulphur free and produces virtually no sulphur dioxide

F Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

11. DIESEL POWER PLANT

Brief technology description
The basic feature of a diesel power plant, is a diesel engine (compression ignition engine) coupled directly to a generator.

Fuel is pumped from a storage tank and fed into a small day tank which supplies the daily need for the engine. Diesel power plants may use different oil products, including heavy fuel oil (or "residual fuel oil") and crude oil. Heavy fuel oil is cheaper than diesel, but more difficult to handle. It has a high viscosity, almost tar-like mass, and needs fuel conditioning (centrifugal separators and filters) and preheating before being injected into the engine.

The temperatures in the engine are very high (1500-2000°C) and therefore a cooling system is required. Water is circulated inside the engine in water jackets and normally cooled in a cooling tower (or by sea water).

The waste heat from the engine and from the exhaust gasses may also be recovered for space heating or industrial processes.

It is also an option, to use the waste heat from diesel exhaust gasses in combined cycle with steam turbine generator. Typically, this is only considered relevant in large-scale power stations (50 MWe or above) with high capacity factors.

Due to relatively high fuel costs, diesel power plants are mainly used in small or medium sized power systems or as peak supply in larger power systems. In small power systems they can also be used in combination (backup) with renewable energy technologies. Several suppliers offer turnkey hybrid power projects in the range from 10 to 300 MW, combining solar PV, wind power, biomass, waste, gas and/or diesel (Ref 1).

In an idealised thermodynamic process, a diesel engine would be able to achieve an efficiency of more than 60%. Under real conditions, plant net efficiencies are 45-46%. For combined cycle power plants efficiencies of 50% are reached (ref. 5).

Input
Diesel engines may use a wide range of fuels including: crude oil, heavy fuel oil, diesel oil, emulsified fuels (emulsions composed of water and a combustible liquid), and biodiesel fuel. Engines can also be converted to operation on natural gas.

Output
Power.

Typical capacities
Up to approx. 300 MWe. Large diesel power plants (>20 MWe) would often consists of multiple engines in the size of 1-23 MWe (ref 5)

Ramping configurations
Combustion engine power plants do not have minimum load limitations and can maintain high efficiency at partial load due to modularity of design – the operation of a subset of the engines at full load. As load is decreased, individual engines within the generating set can be shut down to reduce the output. The engines that remain operating can generate at full load, maintaining high efficiency of the generating set.

Diesel power plants can start and reach full load within 2-15 minutes (under hot start conditions). Synchronization can take place within 30 seconds. This is beneficial for the grid operator, when an imbalance between supply and demand begins to occur.

Engines are able to provide peaking power, reserve power, load following, ancillary services including regulation, spinning and non-spinning reserve, frequency and voltage control, and black-start capability (ref 2, ref 3).

Advantages/disadvantages
Advantages

- Minimal impact of ambient conditions (temperature and altitude) on plant performance and functionality
- Fast start-stop
- High efficiency in part load
- Modular technology – allowing most of the plant to generate during maintenance
- Short construction time, example down to 10 months.
- Proven technology with high reliability

Disadvantages

- Diesel engines cannot be used to produce considerable amounts of high-pressure steam, as approx. 50% of the waste heat is released at lower temperatures.
- Expensive fuel.
- High environmental impact on NOx and SO2.

Environment
Emissions highly depend on the fuels applied, fuel type and its content of sulphur etc.

Emissions may be reduced via fuel quality selection and low emission technologies or by dedicated (flue gas) abatement technologies such as SCR (selective catalytic reduction) systems. Modern large-scale diesel power stations apply lean-burn gas engines, where fuel and air are pre-mixed before entering the cylinders, which reduces NOX emissions.

With SCR technology, NOx levels of 5 ppm, vol, dry at 15% O2 can be attained (ref. 5).

Research and development
Diesel engines are a very well-known and mature technology – i.e. category 4.

Short start-up, fast load response and other grid services are becoming more important as more fluctuating power sources are supplying power grids. Diesel engines have a potential for supplying such services, and R&D efforts are put into this (ref. 6).

Prediction of performance and cost
Diesel power plants is a mature technology and only gradual improvements are expected.

According to the IEA's 2 and 4 DS scenarios the global installed capacity of oil fired plants will decrease in the future and therefore, even when considering replacement of existing oil power plants, the future market for diesel power plants is going to be moderate. Taking a learning curve approach to the future cost development, this also means that the price of diesel power plants can be expected to remain at more or less the same level as today.

Diesel engines may however also run on natural gas and their advantageous ramping abilities compared to gas turbines make them attractive as backup for intermittent renewable energy technologies. This may pave the way for a wider deployment in future electricity markets.

A recent 37 MW project on the Faeroe Island has been announced to cost approx. 200 mill. Danish kroner corresponding to a price of 0.86 mill. USD/MWe (Ref 7). PLN are planning costs of 0.75 mill. USD/MWe for gas engines (18 MWe per unit).

In the data sheet we consider a 100MWe oil fired power plant consisting of 5 units, at 20 MWe each and an estimated price of 0.8 mill. USD/MWe.

Examples of current projects
The Arun 184 MW power plant located in the Aceh Special District in northern Sumatra, consist of 19 Wärtsilä 20V34SG engines running on liquefied natural gas (LNG). Operating at peak load/stand-by & emergency, Arun will be able to reach full load in around 10-15 minutes. (ref. 4.).

References
The description in this chapter is to a great extend from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion".* The following sources are used:

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6. Danish Energy Agency, 2016. Technology Data for Energy Plants, August 2016, https://ens.dk/sites/ens.dk/files/Analyser/technology_data_catalogue_for_energy_plants_-_aug_2016._update_june_2017.pdf)
7. BWSC once again to deliver highly efficient power plant in the Faroe Islands. http://www.bwsc.com/News---Press.aspx?ID=530&PID=2281&Action=1&NewsId=206

Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Diesel engine (using fuel oil)								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	20	20	20						1
Generating capacity for total power plant (MWe)	100	100	100						
Electricity efficiency, net (%), name plate	46	47	48						1
Electricity efficiency, net (%), annual average	45	46	47	43	47	45	52		1
Forced outage (%)	3	3	3						
Planned outage (weeks per year)	1	1	1						2
Technical lifetime (years)	25	25	25						2
Construction time (years)	1.0	1.0	1.0						2
Space requirement (1000 m^2/MWe)	0.05	0.05	0.05						2
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-						
Capacity factor (%), incl. outages	-	-	-						
Ramping configurations									
Ramping (% per minute)	25	25	25						
Minimum load (% of full load)	6.0	6.0	6.0					A	1
Warm start-up time (hours)	0.05	0.05	0.05						1
Cold start-up time (hours)	0.3	0.3	0.3						
Environment									
PM 2.5 (gram per Nm^3)	20	20	20					B, C	3.4
SO_2 (degree of desulphuring, %)	0	0	0					C	3,4
SO_2 (g per GJ fuel)	224	224	224					C	3.4
NO_X (g per GJ fuel)	280	280	280					C	3.4
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)	0.80	0.80	0.78	0.70	0.90	0.65	0.85	D	6.7
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)	8,000	8,000	7,760						2
Variable O&M ($/MWh)	6.4	6.0	5.8						2
Start-up costs ($/MWe/start-up)	-	-	-						

References:

1 Wärtsila, 2011, "White paper Combustion engine power plants", Niklas Haga, General Manager, Marketing & Business Development Power Plants

2 Danish Energy Agency, 2016, "Technology Data for Energy Plants"

3 Minister of Environment, Regulation 21/2008

4 The International Council on Combustion Engines, 2008: Guide to diesel exhaust emissions control of NOx, SOx, particles, smoke and CO2

5 http://www.bwsc.com/News---Press.aspx?ID=530&PID=2281&Action=1&NewsId=206

6 BWSC once again to deliver highly efficient power plant in the Faroe Islands.

7 PLN, 2017, data provided the System Planning Division at PLN

Notes:

A 30 % minimum load per unit - corresponds to 6 % for total plant when consisting of 5 units

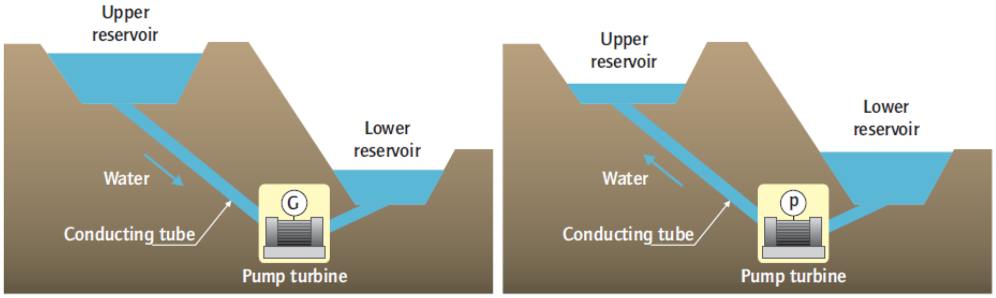
B Total particulate matter

C Typical diesel exhaut emission according to Ref 3 (average of interval) unless this number exceeds the maximum allowed emission according to Minister of Environment Regulation 21/2008. Both SO2 and particulates are dependant on the fuel composition.

D Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

12. HYDRO PUMPED STORAGE

Brief technology description
Pumped storage plants (PSPs) use water that is pumped from a lower reservoir into an upper reservoir when electricity supply exceeds demand or can be generated at low cost. When demand exceeds instantaneous electricity generation and electricity has a high value, water is released to flow back from the upper reservoir through turbines to generate electricity. Pumped storage plants take energy from the grid to lift the water up, then return most of it later (round-trip efficiency being 70% to 85%). Hence, PSP is a net consumer of electricity but provides for effective electricity storage. Pumped storage currently represents 99% of the worlds on-grid electricity storage (ref. 1).



Source: Inage, 2009.

Pumped storage hydropower plants (ref. 2)

A pumped storage project would typically be designed to have 6 to 20 hours of hydraulic reservoir storage for operation. By increasing plant capacity in terms of size and number of units, hydroelectric pumped storage generation can be concentrated and shaped to match periods of highest demand, when it has the greatest value. Both reservoir and pumped storage hydropower are flexible sources of electricity that can help system operators handle the variability of other renewable energy sources such as wind power and photovoltaic electricity.

There are three types of pumped storage hydropower (ref. 3):

- Open loop: systems that developed from an existing hydropower plant by addition of either an upper or a lower reservoir. They are usually off stream.
- Pump back: systems that are using two reservoirs in series. Pumping from the downstream reservoir during low-load periods making additional water available to use for generation at high demand periods.
- Closed loop: systems are completely independent from existing water streams – both reservoirs are off-stream.

Pumped storage and conventional hydropower with reservoir storage are the only large-scale, low-cost electricity storage options available today. Pumped storage power plants are currently less expensive than Li-ion batteries. However, pumped storage plants are generally more expensive than conventional large hydropower schemes with storage, and it is often very difficult to find good sites to develop pumped hydro storage schemes.

Interest in pumped storage is increasing, particularly in regions and countries where solar PV and wind are reaching relatively high levels of penetration and/or are growing rapidly (ref. 5). The vast majority of current pumped storage capacity is located in Europe, Japan and the United States (ref. 5).

Currently, pumped storage capacity worldwide amounts to about 140 GW. In the European Union, there are 45 GWe of pumped storage capacity. In Asia, the leading pumped hydropower countries are Japan (30 GW) and

China (24 GW). The United States also has a significant volume of the pumped storage capacity (20 GW) (ref. 6).

Indonesia is currently developing a pumped storage hydropower plant project at West Bandung and Cianjur Regency, West Jawa. The project is called Upper Cisokan Pumped Storage Power Plant. After receiving funding from the World Bank, construction on major works began in 2015 and the first generator will be commissioned in 2019. It will have an installed capacity of 1,040 MW and will be Indonesia's first pumped-storage power plant. As a pumped-storage power plant, the project includes the creation of an upper and lower reservoir; the lower reservoir will be on the Upper Cisokan River a branch of Citarum River while the upper reservoir will be on the Cirumanis River, a branch of the Cisokan River (ref. 7).

Input
Electricity

Output
Electricity

Typical capacities
50 to 500 MW per unit (ref. 12)

Ramping configurations
Pumped storage hydropower plants have a fast load gradient (i.e. the rate of change of nominal output in a given timeframe) as they can ramp up and down by more than 40% of the nominal output per minute. Pumped storage and storage hydro with peak generation are able to cope with high generation-driven fluctuations and can provide active power within a short period of time.

Advantages/disadvantages
Advantage:

- Lower cost compared to other peak load plants (gas and diesel power plants).
- The water can be reused over and over again and thus smaller reservoirs are suitable.
- The process of electricity generation has no emissions.
- Water is a renewable source of energy.
- The reservoirs can be used for additional purposes like water supply, fishing and recreation (ref. 15).

Disadvantages:

- Very limited locations.
- Cost of infrastructure.
- The time it takes to construct is longer than other energy storage options.
- The construction of dams in rivers always has an impact on the environment.

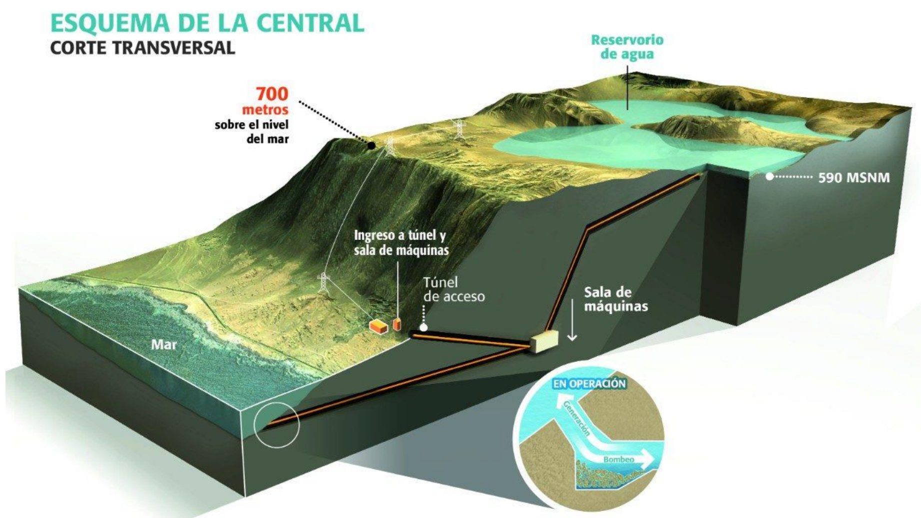
Environment
The possible environmental impacts of pumped storage plants have not been systematically assessed, but are expected to be small. The water is largely reused, limiting extraction from external water bodies to a minimum. Using existing dams for pumped storage may result in political opportunities and funding for retrofitting devices and new operating rules that reduce previous ecological and social impacts (ref. 8). PSP projects require small land areas, as their reservoirs will in most cases be designed to provide only hours or days of generating capacities.

Employment
PLN expected that the Upper Cisokan hydro power plant (pumped storage) would need around 3000 workers to complete. According to current regulation on manpower, two thirds of those workers must be selected from local work force.

Research and development
Hydro pumped storage is like, hydro reservoir power, a well-known and mature technology – i.e. category 4.

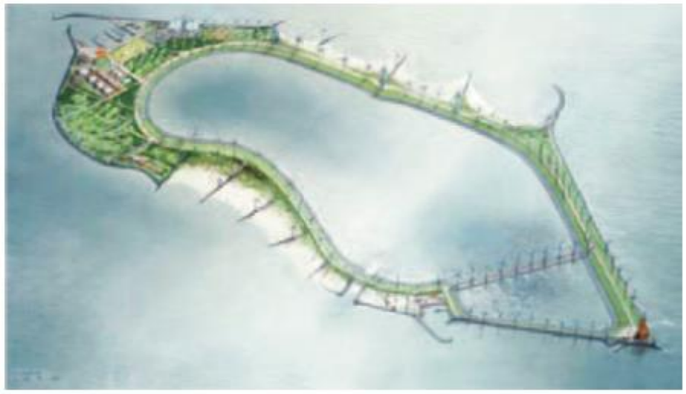
Under normal operating conditions, hydropower turbines are optimized for an operating point defined by speed, head and discharge. At fixed-speed operation, any head or discharge deviation involves some decrease in efficiency. Variable-speed pump-turbine units operate over a wide range of head and flow, improving their economics for pumped storage. Furthermore, variable-speed units accommodate load variations and provide frequency regulation in pumping mode (which fixed-speed reversible pump-turbines provide only in generation mode). The variable unit continues to function even at lower energy levels, ensuring a steady refilling of the reservoir while helping to stabilize the network.

Pumped storage plants can operate on seawater, although there are additional challenges involved compared to operation with fresh water. The 30 MW Yanbaru project in Okinawa was the first demonstration of seawater pumped storage. It was built in 1999 but finally dismantled in 2016 since it was not economically competitive. A 300 MW seawater-based project has recently been proposed on Lanai, Hawaii, and several seawater-based projects have been proposed in Ireland and Chile.



A 300 MW sea water pumped storage hydropower plan in Chile (ref. 13)

A Dutch company, Kema, has further developed the concept of an "Energy Island" to be build off the Dutch coast in the North Sea. It would be a ring dyke enclosing an area 10 km long and 6 km wide (see figure below). The water level in the inner lake would be 32 metres to 40 metres below sea level. Water would be pumped out when electricity is inexpensive, and generated through a turbine when it is expensive. The storage potential would be 1 500 MW by 12 hours, or 18 GWh. It would also be possible to install wind turbines on the dykes, so reducing the cost of offshore wind close to that of onshore, but still with offshore load factors.



Concept of an energy island (ref. 9)

In Germany, RAG, a company that exploited coal mines, is considering creating artificial lakes on top of slag heaps or pouring water into vertical mine shafts, as two different new concepts for PSP (ref. 10)

Examples of current projects
Storage possibilities combined with the instant start and stop of generation makes hydropower very flexible. Pumped storage plants, such as the Grand Maison power station in France, can ramp-up up to 1800 MW in only three minutes. This equals 600 MW/min (ref. 11).

The Fengning Pumped Storage Power Station is a pumped-storage hydroelectric power station currently under construction about 145 km (90 mi) northwest of Chengde in Fengning Manchu Autonomous County of Hebei Province, China. Construction on the power station began in June 2013 and the first generator is expected to be commissioned in 2019, the last in 2021. Project costs are US$1.87 billion. On 1. April 2014, Gezhouba Group was awarded the main contract to build the power station. When complete, it will be the largest pumped-storage power station in the world with an installed capacity of 3600 MW which consists of 12 x 300 MW Francis pump turbines (ref. 14).

As mentioned before Indonesia is building the country's first pumped storage hydropower plant. The power plant will operate by shifting water between two reservoirs; the lower reservoir on the Upper Cisokan River and the upper reservoir on the Cirumamis River which is a right-bank tributary of the Upper Cisokan. When energy demand is high, water from the upper reservoir is sent to the power plant to produce electricity. When energy demand is low, water is pumped from the lower reservoir to the upper by the same pump-generators. This process repeats as needed and allows the plant to serve as a peaking power plant. The power plant will contain four Francis pump-turbines which are rated at 260 MW each for power generation and 275 MW for pumping. The upper reservoir will lie at maximum elevation of 796 m and the lower at 499 m. This difference in elevation will afford the power plant a rated hydraulic head of 276 m. It is expected that the plant will be commercially operational in 2019.

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Data sheets

The following pages contain the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* is related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	Hydro pumped storage								
	2020	2030	2050	Uncertainty (2020)		Uncertainty (2050)		Note	Ref
Energy/technical data				Lower	Upper	Lower	Upper		
Generating capacity for one unit (MWe)	250	250	250	100	500	100	500	A	1,6
Generating capacity for total power plant (MWe)	1000	1000	1000	100	4000	100	4000		1,6
Electricity efficiency, net (%), name plate	80	80	80	75	82	75	82		1,3,5
Electricity efficiency, net (%), annual average	80	80	80	75	82	75	82		1,3,5
Forced outage (%)	4	4	4	2	7	2	7		5
Planned outage (weeks per year)	3	3	3	2	6	2	6		5
Technical lifetime (years)	50	50	50	40	90	40	90		1
Construction time (years)	4.3	4.3	4.3	2.2	6.5	2.2	6.5	B	1
Space requirement (1000 m^2/MWe)	30	30	30	15	45	15	45		1
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	50	50	50	10	100	10	100		2,5
Minimum load (% of full load)	0	0	0	0	0	0	0		2
Warm start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		2
Cold start-up time (hours)	0.1	0.1	0.1	0.0	0.3	0.0	0.3		2
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	0.86	0.86	0.86	0.60	6.0	0.60	6.0	C,E	1,3,4
- of which equipment (%)	30%	30%	30%	20%	50%	20%	50%		7
- of which installation (%)	70%	70%	70%	50%	80%	50%	80%		7
Fixed O&M ($/MWe/year)	8,000	8,000	8,000	4,000	30,000	4,000	30,000		3,4,6.7
Variable O&M ($/MWh)	1.3	1.3	1.3	0.5	3.0	0.5	3.0		1,7
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Size of reservoir (MWh)	10,000	10,000	10,000	3,000	20,000	3,000	20,000	D	1,6
Load/unload time (hours)	10	10	10	4	12	4	12	D	1,6

References:

1 PLN, 2017, data provided the System Planning Division at PLN

2 Eurelectric, 2015, "Hydropower - Supporting a power system in transition".

3 Lazard, 2016, "Lazard's Levelised Cost of Storage – version 2.0".

4 MWH, 2009, Technical Analysis of Pumped Storage and Integration with Wind Power in the Pacific Northwest

5 U.S. Department of Energy, 2015, "Hydropower Market Report".

6 Connolly, 2009, "A Review of Energy Storage Technologies - For the integration of fluctuating renewable energy".

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Notes:

A Size per turbine.

B Uncertainty (Upper/Lower) is estimated as +/- 50%.

C Numbers are very site sensitive. There will be an improvement by learning curve development, but this improvement will equalized because the best locations will be utilized first. The investment largely depends on civil work.

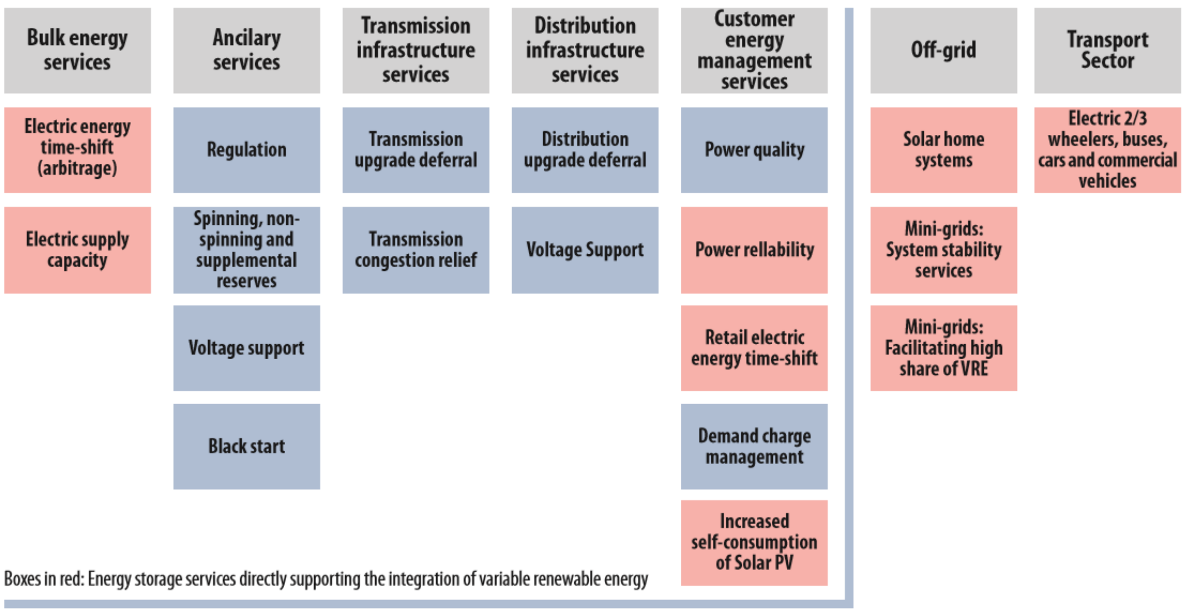
D The size of the total power plant and not per unit (turbine).

E Investment cost include the engineering, procurement and construction (EPC) cost. See description under Methodology.

13. BATTERIES (LI-ION)

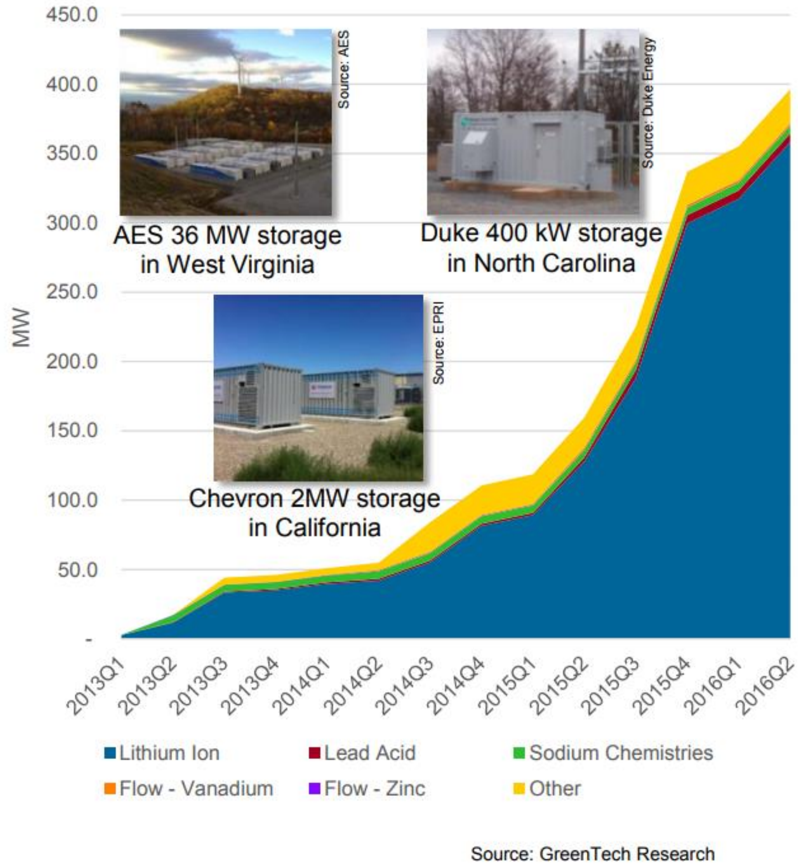
Brief technology description
With increasing shares of renewable energy in power systems, electric storage in batteries can play an important role. The potential applications of batteries in electricity systems are very broad, ranging from supporting weak distribution grids, to provision of bulk energy service or off-grid solutions (see figure below).

This technology description focuses on batteries for provision of *bulk energy services*, i.e. time-shift over several hours – for example moving PV generation from day to night hours – and delivery of peak power capacity.



The range of services that can be provided by electricity storage (ref. 41).

There are a high number of different battery technologies in the market, including lead-acid batteries, high temperature sodium sulphur (NaS), sodium nickel chloride batteries and flow battery technologies (vanadium redox flow and zinc-bromine). Lithium ion batteries (LIB) have however completely dominated the market for grid scale energy storage solutions in the last three years and appear to be the dominating battery solution (see figure below). Total LIB based energy storage systems (ESS) currently installed (or announced / being developed) amounts to a cumulative 3650 MW and 2300 MWh worldwide in more than 600 locations (ref. 10). For this reason, this chapter focuses on LIB, as the ‘representative’ battery for the future.



Dominance of Li-ion battery (LIB) based grid-scale energy storage solutions installed during last few years (cumulative since 2013). Current (Sept. 2017) global aggregate capacity of 1MW or above LIB energy storage systems is 1500 MW – four times the value 2016Q2 in the figure (ref. 10).

The charging and discharging of the individual cells in the LIB is controlled by an electronic battery management system to optimize cell utilization and degradation while delivering designated load/charging current. The fast lithium ion transport and small diffusion distance due to the lamellar architecture of components inside the cell ensure that the response time for LIB is only a few milliseconds (ref. 1). It also has a low self-discharge rate of only 0.1–0.3% per day and good cycle efficiency of 97% (ref. 8).

Charging and discharging rates of LIB is often measured in C-rates. For example, discharging a cell in 20 minutes, 1 hour and 2 hours would be reported as 3C, C and C/2. Higher C-rate is often possible beyond that suggested for the battery pack, but would lead to degradation of electrode materials and capacity faster than envisioned (ref. 9). For grid connected LIB systems, the C-rate is managed between 4C and C/4 (ref. 10). Generally, for the same chemistry/construction, a battery going through a 15 minute full discharge will have a lower cycle life (and thereby lifetime) than a similar battery used for a 1 hour full discharge cycle.

The feasibility of a wide range of charge/discharge rates allow regulation through LIB based storage. LIB does not suffer from the memory effect issue (the effect of batteries gradually losing their maximum energy capacity if they are repeatedly recharged after being only partially discharged) and can be used for variable depths of discharge at short cycles without losing capacity (ref. 11).

Input
Electricity

Output
The output is electricity.

The efficiency of Li-ion battery cells can reach close to 100%. However, AC-DC conversion and energy demand from the control electronics leads to a grid-grid efficiency (AC-AC) of about 85% as observed in the Maui, Hawaii site, where LIB is used for wind power smoothing. Frequency regulation or capacity management usage require fast short cycle charge-discharge and reduces round trip efficiency. While time shift application (cycling once in 24h) provides better efficiency. Since this catalogue focuses on the bulk energy services for – example moving PV generation from day to night hours – then the better efficiency would be the case.

Typical capacities
Existing/planned systems range from small 1 kW systems to 100 MW (400 MWh).

Ramping configurations
Li-ion batteries (LIB) installations are very flexible in terms of power/energy capacity and time of discharge. Stored energy in the installations can be released within 10 minutes to 25 hours. The LIB energy storage system (EES) used for black start and power ramping has a discharge time of 2 hours or less. For example, AES Laurel Mountain is a 98 MW wind power generation plant located in Belington, West Virginia. Frequency regulation for this firm is provided by AES with a A123 System's advanced lithium ion battery technology. Although the power rating is very high at 32 MW, it only takes 15 minutes to discharge fully. Similar wind power balancing ESS using LIB is being built by TESLA for the French renewable company Neoen's Hornsdale Wind Farm near Jamestown, Australia with a capacity of 100 MW/129 MWh.

On the other hand, time shifting needs long term storage and discharge, up to 6 hours or more. For example, an AES installed LIB facility in San Diego can feed the grid 37.5 MW of power for continuously 4 hours and be used for time shift application.

Advantages/disadvantages
Advantages/disadvantages are considered in relation to other battery technologies:

Advantages:

- Li-ion batteries (LIB) modules are completely maintenance free and can work in harsh environments, thus after installation costs are minimized.
- LIB have high energy and power density medium-to-long cycle life and can deliver a wide range of rate capabilities.

- Round trip energy efficiency is also best for LIB among commercially scalable battery chemistries. Some batteries like NiCd/Ni-MH loose capacity if not fully of discharged. This is called memory effect. LIB do not suffer from memory effect and have low self-discharge.
- Combination of high power and energy density and very short response time (20 ms) enables usage of LIB in both power intensive applications as frequency regulation and energy intensive applications like time shift. Lack of memory effect allows combined short and deep discharge usage like ramp control and electricity bill management at the same site.
- LIB have a relatively long cycle life compared to many other battery chemistries, which lowers levelized cost of storage by amortizing the higher installation expenses over the lifetime.

Disadvantages:
Li-ion batteries (LIB) have a relatively small number of technical disadvantages.

- Electrode materials are prone to degradation if overcharged and deep discharged repeatedly. This can be managed by active battery management systems.
- Continuous short cycle usage like frequency regulation lower the overall lifetime of the battery.
- Safety issues from thermal runaway are of concern. The possibility of such breakdown increases with higher operating temperature and overcharging.
- The electrolyte used has s limited electrochemical stability window. Beyond this a exothermic redox reaction takes place between oxygen released from a cathode and electrolyte molecule and the battery might catch fire (ref. 21). During a thermal runaway, the high heat of one cell can spread to the next cell, causing it to become unstable as well.
- Stability of cathode materials in contact with electrolyte is better for phosphate cathodes than oxide cathodes but phosphate based batteries deliver lower potential. Thermal runaway can be suppressed using inhibitors (ref. 22).
- With LIB demand increasing exponentially every year, the supply of raw materials and incremental costs are the main concerns. Lithium extraction has the potential for geopolitical risks because the world’s known resources of easily extractable lithium are largely concentrated in three South American countries: Chile, Bolivia, and Argentina (ref. 23), but the limited availability of cobalt resources remain the biggest concern.

Environment
Li-ion batteries (LIB) contains toxic cobalt and nickel oxides as cathode materials and thus need to be meticulously recycled although the market price of component materials like lithium/cobalt is still not high enough for making it economically beneficial. Unlike portable electronics, large installations help enforce recycling regulations.

Lithium resource depletion from fast adoption of LIB in electric vehicles and utility scale storage is a concern (ref. 24). US-EPA reported that across the battery chemistries, the global warming potential impacts attributable to the LIB production is substantial (including energy used during mining).

Research and development
The Li-ion battery (LIB) have been well-known for decades, but as an energy storage system (ESS) for the power grid it has first been utilized within the last couple of years, and thereby moved from the pioneer phase (category

2) to the commercial phase, but with significantly development potential (category 3). Therefore, there is still a significantly potential for R&D.

Due to the economic and technological impact, a wide range of government and industry-sponsored research is taking place across the world towards the improvement of Li-ion batteries (LIB) at material and system level. Higher energy density is achievable by discovering new cathode with higher electrochemical potential and anode/cathode materials, which can intercalate more lithium per unit volume/weight. Higher electrochemical potential for cathode materials also need to be matched by the electrochemical stability of the electrolyte used with it. Thus, research in new electrolyte systems are also needed. Electrolytes with better chemical stability also leads to lower chances of thermal runaway. Improved power capacity is obtained if lithium ion movement is faster inside the electrode and the electrolyte materials. In short, cathodes with high electrochemical potential, anodes with low electrochemical potential, cathode/anodes with high lithium capacity, electron/lithium transport, electrolytes with large electrochemical stability window and fast lithium transport is the desirable direction in LIB research.
Great progress has been made in the direction of new cathode materials and significant improvements have been achieved in terms of voltage and energy density. A nickel phosphate (ref. 25) based cathode can operate at 5.5 V (compared to 3.7 V of cobalt oxide cathodes), but a complimentary electrolyte is not available. On the anode side, silicon based anodes can improve upon carbon based anodes for intercalation capacity by up to 10 times. But stability for long term operation has remained an issue (ref. 26). On the electrolyte side, ionic liquids are being researched for safer high potential operation (ref. 27).

Prediction of performance and cost
LIB installations for utility operation from major companies like Samsung SDI/TESLA is modular and scalable. Data for Samsung SDI 44S13P modules at 142 kWh, 3C-rate (426 kW) and M8994 E2 prismatic cells are used for power/energy/efficiency numbers. Modular systems that have been used by TESLA to create 80 MWh storage system within 3 months (ref. 29). Such scalability is a key feature of all major battery module providers like Samsung SDI, TESLA, Hitachi chemical etc. Thus, for modeling linear scaling of energy and power capacity expected. The round trip efficiency considered here (88%) is taken from TESLA Powerpack data for AC to AC including all losses.

Due to lack of specific daily discharge loss data, generally accepted information obtained from published journal articles is used as standard (ref. 8). Due to the long-term maintenance free operation of modular battery packs, outages are nil. Lifetime data for usage time/cycle life at 75% discharge cycle provided by Samsung SDI (8000 cycles) (ref. 7). Partial charge discharge based regulatory application will give much higher number of cycles (ref. 18). Samsung SDI also suggests operation between C/2 to 3C rate, which provides 6 times higher power for the regulation purpose. 10C rated long lifetime battery (ref. 30) is under development and 20C-60C capable batteries (ref. 31) are being experimented upon. Thus, we expect to see commercial 5C rate batteries by 2020 and 10C rate batteries by 2030 for regulation applications. Ramp capacities are calculated from the rated discharge of C/2 and power application discharge rates at 3C/5C/10C in 2017/2020/2030.

Cost 2017 and 2020
The current cost of battery modules (C/2 rate) from TESLA is reportedly priced at US$250/kWh as informed by its CEO Elon Musk (ref. 32) and the price may drop as low as US$100/kWh and US$80/kWh in 2020 and beyond respectively, assuming the production does not become limited by availability of resources and scalability limitations (ref. 33). AUDI CTO also claimed to buy LIB packs for € 100/kWh for electric vehicles (EV) applications. It is difficult to obtain actual installation costs, but LAZARD energy storage report (ref. 34) points to US$87/kWh of installation cost. This is added to the pack cost for estimation. The same report provides the O&M cost of US$7/year/kWh. High rate capability for the same energy capacity battery leads to cheaper per MW cost. Energy and power capacity as well as price increases linearly due to the modular system. Specific power (420

W/kg) and energy density (140 Wh/kg) is calculated from data provided by Samsung SDI M8994 E2 prismatic cells (ref. 7).

Similar to the semiconductor industry, improvements in LIB has been exponential (ref. 35) with a price reduction of ~15%/year. Certain price models predict that it could go as low as ~76US$/kWh by 2020 (ref. 35), but these projections should be used cautiously. Demand from EV and electronic industry have helped optimize manufacturing and supply chains to an unprecedented scale. This has reduced prices fast over the last 20 years. Further improvement came from R&D knowledge in high performance materials transferring to commercialization. It is assumed that energy density will improve in 2030 by ~50% due to materials improvement and rated power capacity also considering similar discharge rate.

Energy efficiency is expected to be the same for battery chemistry (3% loss) and the AC-DC conversion system should have noticeable improvements due to better solid-state converters (overall 4% improvement by 2030).

Currently, commercial systems from Samsung SDI have a 8000-cycle 15-year lifetime. More stable electrode materials (e.g. polyanion cathode and titanate anode) and better big data based management of battery systems are poised to bring at least 50% increase in cycle life and lifetime.

Modular manufacturing and automated installation capabilities can drastically cut down on system setup time to few weeks from current ~3 months, as demonstrated by TESLA.

As the C-rate capacity of batteries increases to 10C by 2030, the regulation capacity will increase linearly (10C ramp vs C/2 operation) and power capacity investment costs will drop. Although module costs will decrease as suggested by Elon Musk CEO of TESLA Inc (ref. 32), counterbalancing effects from more expensive engineering and further automation would keep installation cost and O&M cost (currently US$79/kWh) at a similar level or slightly higher. Power density will follow the improved energy capacity at same C-rate.

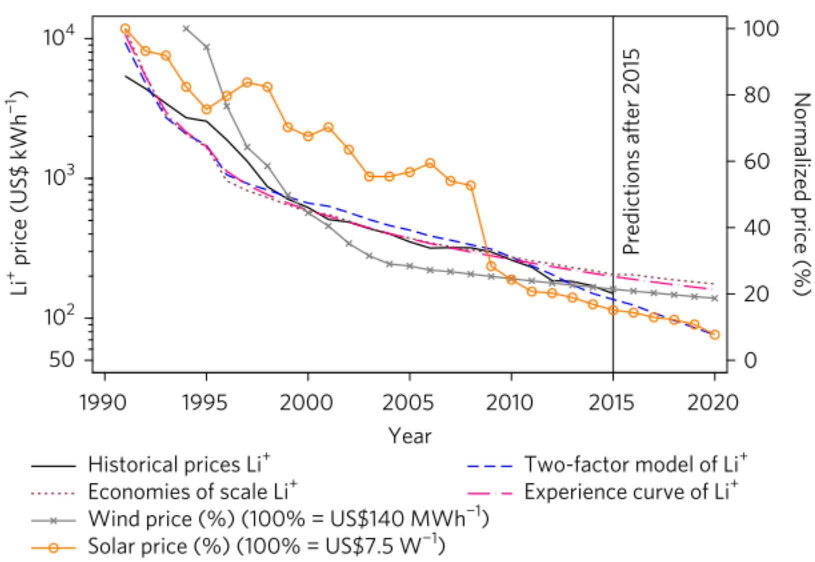


Figure 1: Exponential decrease in LIB prices along with renewable generation. (ref. 35)

Data presented in the data sheet are from specific cases and publicly available sources. Better-negotiated prices are most possibly accessible to project managers. On the other hand, charge/discharge characters assumed for the data sheet might not be accessible at scale, when connected to the grid due to technical limitations. These are future projected numbers. Uncertainty in future development of technology and commercialization pins the accuracy of these suggested numbers for LIB energy storage systems.

Uncertainty in future data

Development in LIB has been rapid in the last few years and upgrades in manufacturing capacity and technologies have been astounding. This is aided by the explosion of the requirements in the area of EV and portable electronics. Large R&D efforts are accelerating the progress, unlike any other storage technologies. For example, development in 6V capable electrolytes, vanadate cathodes and silicon based anodes can increase the electrochemical potential by 70% and Li-capacity by 3 times – leading to 5-fold increases in the energy density, but these technologies are many years from commercialization. In addition, a polymer gel electrolyte based battery has been developed that has a cycle life of 200,000 at 96% efficiency (ref. 36). Commercialization of such technology can make LIB systems last for centuries. For such a rapidly progressing area, it is not possible to propose what is in store for us by 2050.

Examples of current projects

According to the energy storage system (ESS) installation database (ref. 10), 49 plants each with a power capacity of 10 MW or above are in operation with a combined power capacity of 1200 MW. 31 of these ESS installations have frequency regulation as primary or secondary service. The duration for a full discharge is less than 40 minutes for majority of such installations and for 20% the duration time is between 1 and 4 hours. Among those large installations, ESS with 40% total capacity is in the US and 30% in South Korea. The technology providers include A123 systems, LG Chem, BYD, Toshiba, Samsung SDI etc.

- AES/Samsung SDI/Parker Hannifin. 30 MW and 120 MWh (bulk energy service). SDG&E Escondido, San Diego, USA. From 2017. (ref. 10)
- Samsung SDI/GE. 30 MW and 20 MWh (black start and frequency regulation). Imperial Irrigation District, El Centro, California, USA. From 2016. (ref. 10)
- Toshiba. 40 MW and 40 MWh (bulk energy service for RE). Minamisoma, Fukushima Prefecture, Japan. From 2016. (ref. 10)

Picture of the 40 MW and 40 MWh energy storage system in Fukushima, Japan.

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The description in this chapter is to a great extend based on from the Danish Technology Catalogue *"Technology Data on Energy Plants - Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion"*, draft technology chapter on *"Lithium ion batteries for grid scale storage"* prepared by the Danish Technical University. The following are sources are used:

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Data sheets

The following pages content the data sheets of the technology. All costs are stated in U.S. dollars (USD), price year 2016. The *uncertainty* it related to the specific parameters and cannot be read vertically – meaning a product with lower efficiency do not have the lower price or vice versa.

Technology	**Batteries - Lithium-ion (utility scale)**								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)	0.036	0.036	0.036					B	
Generating capacity for total power plant (MWe)	10	10	10					B	
Electricity efficiency, net (%), name plate	88	88	88					A,I	1,2
Electricity efficiency, net (%), annual average	88	88	88					A,I	1,2
Forced outage (%)	0	0	0	-	-	-	-		
Planned outage (weeks per year)	0	0	0	-	-	-	-		
Technical lifetime (years)	15	18	23	-	-	-	-	D	1
Construction time (years)	0.25	0.25	0.25						7
Space requirement (1000 m^2/MWe)	-	-	-	-	-	-	-		
Additional data for non thermal plants									
Capacity factor (%), theoretical	-	-	-	-	-	-	-		
Capacity factor (%), incl. outages	-	-	-	-	-	-	-		
Ramping configurations									
Ramping (% per minute)	1,200	2,000	4,000					F	4,6,8
Minimum load (% of full load)	0	0	0						4,6,8
Warm start-up time (hours)	-	-	-	-	-	-	-		
Cold start-up time (hours)	-	-	-	-	-	-	-		
Environment									
PM 2.5 (gram per Nm^3)	-	-	-	-	-	-	-		
SO_2 (degree of desulphuring, %)	-	-	-	-	-	-	-		
NO_X (g per GJ fuel)	-	-	-	-	-	-	-		
CH_4 (g per GJ fuel)	-	-	-	-	-	-	-		
N_2O (g per GJ fuel)	-	-	-	-	-	-	-		
Financial data									
Nominal investment (M$/MWe)	-	-	-	-	-	-	-	C	
- of which equipment	74	53	43						
- of which installation	26	47	57						
Fixed O&M ($/MWe/year)	-	-	-	-	-	-	-		4
Variable O&M ($/MWh)	0	0	0	0	0	0	0		
Start-up costs ($/MWe/start-up)	-	-	-	-	-	-	-		
Technology specific data									
Storage capacity for one unit (MWh)	0.142	0.142	0.142					B,I	1-5
Nominal investment (M$/MWh)	0.25	0.14	0.13					B,G	1,2,4
Fixed O&M ($/MWh/year)	7,000	7,000	7,000						4
Lifetime in total number of cycles	8,000	10,000	10,000					H	1

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Notes:

A Efficiency defined as the 'round-trip efficiency'.

B Power and energy output can be scaled linearly by utilizing many modules (up to 100MW has been demonstrated). Output capacity expansion can be done reprogramming the management unit without any new battery module.

C See under: Nominel investment (M$/MWh)

D Samsung SDI 2016 whitepaper on ESS solutions provide 15 year lifetime for current modules operating at C/2 to 3C. Steady improvement in battery lifetime due to better materials and battery management expected

E Powerpack based 80 MWh facility installed in less than 3 months by TESLA. Ramped up production and automation will further lower this time to few weeks by 2030

F 3C rate operation as suggested by Samsung SDI whitepaper lead to 6 times higher power than normal C/2 operation. 10C-60C rate capable batteries are in research and development state. Commercialization of 5C and 10C batteries for frequency regulation application anticipated by 2020 and 2030 respectively.

G Tesla CEO Elon Musk suggested US$250/kWh cost for 100MW scale Powerpack system now and less than US$100/kWh (2020) and less than US$80/kWh after that. Audi is buying battery packs at € 100/kWh now. Historical price development models also points to US$125/kWh by next year and US$100/kWh by 2020.

H Current commercial module from Samsung SDI has 8,000 cycles full charge lifetime. It is expected to increase with time.

I Data for single Samsung SDI 44S13P module charging/discharging at 3C rate is used for 2015 and 2020. By 2020/2030, 5C/10C rate capacity envisioned from better materials and 4 % efficiency improvement from better AC-DC converter.

APPENDIX: METODOLOGI (BAHASA)

Pengantar metodologi

Teknologi yang dijelaskan dalam katalog ini mencakup teknologi yang telah matang dan teknologi yang diharapkan akan meningkat secara signifikan dalam beberapa dekade mendatang, baik dari sisi kinerja maupun biaya. Hal ini menunjukkan bahwa harga dan kinerja beberapa teknologi dapat diperkirakan dengan tingkat kepastian yang agak tinggi. Sedangkan dalam kasus teknologi lain, biaya dan kinerja saat ini maupun di masa depan dikaitkan dengan tingkat ketidakpastian yang tinggi. Semua teknologi telah dikelompokkan dalam satu dari empat kategori pengembangan teknologi (dijelaskan dalam bagian tentang Penelitian dan Pengembangan) yang menunjukkan kemajuan teknologinya, perspektif pengembangan masa depannya, dan ketidakpastian terkait proyeksi data biaya dan kinerja.

Batasan untuk data biaya dan kinerja adalah aset pembangkitan ditambah infrastruktur yang diperlukan untuk memasok energi ke jaringan utama. Untuk listrik, batasan ini adalah gardu terdekat ke grid transmisi. Hal ini menunjukkan bahwa suatu Mega Watt listrik merupakan besaran listrik bersih yang dipasok, yaitu jumlah kotor pembangkitan dikurangi jumlah listrik tambahan yang digunakan di pembangkit. Oleh karena itu, efisiensi juga efisiensi bersih.

Kecuali dinyatakan lain, teknologi termal dalam katalog diasumsikan dirancang dan beroperasi kira-kira. 6000 jam beban penuh pembangkitan setiap tahunnya (faktor kapasitas 70%). Beberapa pengecualian adalah fasilitas pembangkit limbah padat perkotaan dan pembangkit listrik tenaga panas bumi, yang dirancang untuk beroperasi terus menerus, yaitu sekitar 8000 jam beban penuh setiap tahun (faktor kapasitas 90%).

Masing-masing teknologi dijelaskan dalam lembar teknologi terpisah, mengikuti format yang dijelaskan di bawah ini.

Deskripsi Kualitatif

Deskripsi kualitatif menggambarkan karakteristik kunci dari teknologi tersebut sesingkat mungkin. Paragraf berikut disertakan jika ditemukan hal yang relevan untuk teknologi.

Informasi Kontak
Detail kontak jika hal pembaca telah mengklarifikasi pertanyaan ke lembar data. Bila tidak ada keputusan lain, Dewan Energi Nasional adalah entitas kontak untuk katalog.

Deskripsi Teknologi
Deskripsi singkat untuk non-insinyur tentang bagaimana teknologi bekerja dan untuk tujuan apa.

Input
Bahan baku utama, terutama bahan bakar, dibutuhkan oleh teknologi tersebut.

Output
Output dari teknologi dalam katalog adalah listrik. Output lain seperti proses panas bisa disebutkan disini.

Kapasitas Khas

Kapasitas yang ditetapkan adalah untuk mesin tunggal (misalnya turbin angin tunggal atau turbin gas tunggal), dan juga untuk pembangkit listrik total yang terdiri dari banyak mesin seperti ladang angin. Kapasitas total pembangkit listrik seharusnya merupakan instalasi khas di Indonesia.

Konfigurasi Landaian (Ramping) dan Layanan Sistem Tenaga Lainnya
Deskripsi singkat tentang konfigurasi landaian untuk teknologi pembangkit listrik, yaitu karakteristik beban-bagian, seberapa cepat mereka dapat memulai (start up), dan seberapa cepat mereka dapat merespons perubahan permintaan (ramping)

Keuntungan dan Kerugian
Keuntungan dan kerugian tergantung pada teknologi yang setara. Keuntungan generik diabaikan; misalnya, teknologi energi terbarukan mengurangi risiko iklim dan meningkatkan keamanan pasokan.

Lingkungan
Karakteristik lingkungan tertentu disebutkan, mis. emisi khusus atau jejak ekologis utama.

Ketenagakerjaan
Bagian ini menjelaskan tentang persyaratan tenaga kerja dari masing-masing teknologi dalam proses pembuatan dan instalasi serta selama operasi. Hal ini akan dilakukan baik dengan contoh-contoh maupun mencantumkan persyaratan dalam peraturan perundang-undangan untuk kandungan lokal (Peraturan Menteri Perindustrian Nomor 54/M-IND/PER/3/2012 dan Nomor 05/M-IND/PER/2/2017). Ini diwajibkan untuk proyek yang dimiliki atau didanai oleh pemerintah atau perusahaan milik pemerintah untuk mengikuti peraturan ini. Tabel di bawah merangkum peraturan tersebut.

Rangkuman Peraturan mengenai kandungan local.

Jenis	**Kapasitas**	**Kandungan Lokal (%)**		
		Barang (minimum)	**Jasa**	**Kombinasi Barang dan Jasa (minimum)**
PLTU	Up to 15 MW	67.95	96.31	70.79
	15 – 25 MW	45.36	91.99	49.09
	25 – 100 MW	40.85	88.07	44.14
	100 – 600 MW	38.00	71.33	40.00
	> 600 MW	36.10	71.33	38.21
PLTA	Up to 15 MW	64.20	86.06	70.76
	15 – 50 MW	49.84	55.54	51.60
	50 – 150 MW	48.11	51.10	49.00
	> 150 MW	47.82	46.98	47.60
PLTP	Up to 15 MW	31.30	89.18	42.00
	5 – 10 MW	21.00	82.30	40.45
	10 – 60 MW	15.70	74.10	33.24
	60 – 110 MW	16.30	60.10	29.21

	> 110 MW	16.00	58.40	28.95
PLTG	Up to 100 MW	43.69	96.31	48.96
PLTGU	Up to 50 MW	40.00	71.53	47.88
	50 – 100 MW	35.71	71.53	40.00
	100 – 300 MW	30.67	71.53	34.76
	> 300 MW	25.63	71.53	30.22
PLTS	Decentralized off-grid	39.87	100.00	45.90
	Centralized off-grid	37.47	100.00	43.72
	Centralized on-grid	34.09	100.00	40.68

Penelitian dan Pengembangan
Bagian ini harus mencantumkan tantangan paling penting dari perspektif penelitian dan pengembangan. Perspektif penelitian dan pengembangan khususnya dapat ditekankan jika relevan.

Bagian ini juga menjelaskan seberapa jauh kematangan teknologi.

Tahun dasar yang digunakan dalam proyeksi katalog ini adalah 2020. Selain itu kondisi yang diharapkan adalah adanya penurunan biaya dan perbaikan kinerja di masa yang akan datang.

Bagian ini memberikan asumsi-asumsi yang mendasari perbaikan yang diasumsikan dalam lembar data untuk tahun 2030 dan 2050.

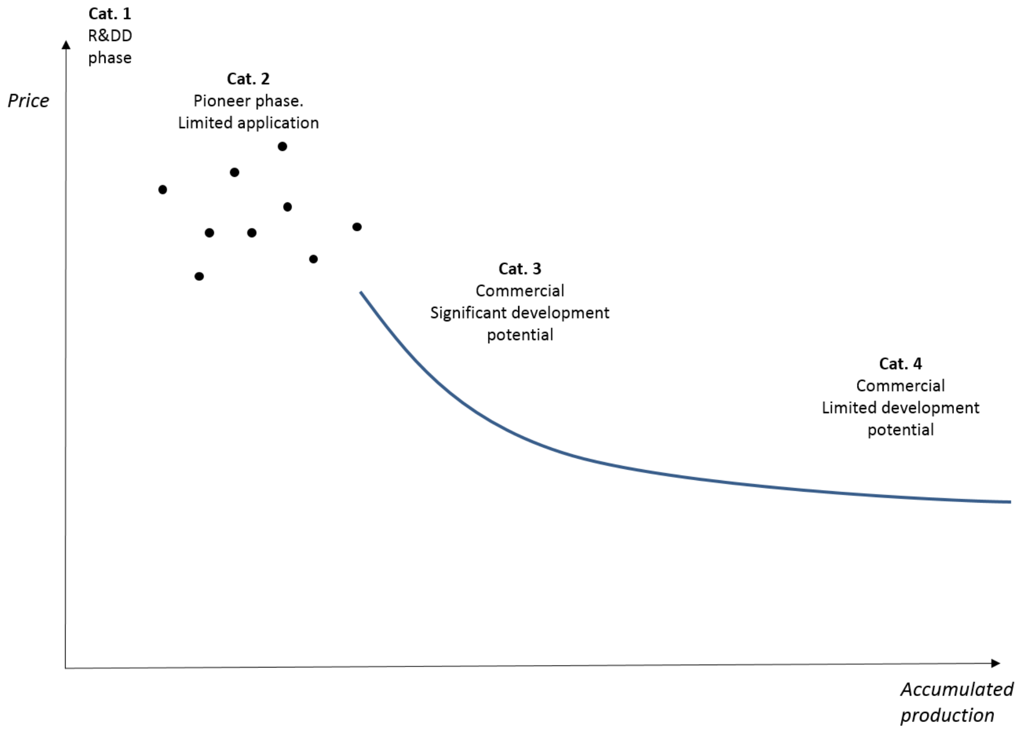
Potensi peningkatan teknologi terkait dengan tingkat kematangan teknologi. Oleh karena itu, bagian ini juga mencakup deskripsi kemajuan komersial dan teknologi. Teknologi dikategorikan dalam salah satu dari empat tingkat kedewasaan teknologi berikut.

Kategori 1. Teknologi yang masih dalam tahap penelitian dan pengembangan. Ketidakpastian terkait harga dan kinerja hari ini dan ke depan, sangat signifikan.

Kategori 2. Teknologi dalam fase perintis. Melalui fasilitas *demo-plant* atau semi-commercial plants. Hal ini telah dibuktikan bahwa teknologi tersebut berhasil. Karena keterbatasan aplikasi, harga dan kinerja masih terkait dengan ketidakpastian yang tinggi, pengembangan dan penyesuaian masih diperlukan. (misalnya gasifikasi biomassa).

Kategori 3. Teknologi komersial dengan penyebaran moderat sejauh ini. Harga dan kinerja teknologi saat ini sudah cukup dikenal. Teknologi ini dianggap memiliki potensi pengembangan yang signifikan dan oleh karena itu ada tingkat ketidakpastian yang cukup besar terkait dengan harga dan kinerja di masa depan (misalnya turbin angin lepas pantai)

Kategori 4. Teknologi komersial, dengan penyebaran besar sejauh ini. Harga dan kinerja teknologi saat ini sudah diketahui, biasanya hanya akan terjadi peningkatan bertahap. Oleh karena itu, harga dan kinerja masa depan juga dapat diproyeksikan dengan tingkat kepastian cukup tinggi (misal: tenaga batubara, turbin gas).



Tahap pengembangan teknologi. Korelasi antara akumulasi produksi (MW) dan harga.

Contoh Teknologi Standar Pasar
Inovasi teknologi terbaru dalam operasi komersial skala penuh harus disebutkan dalam katalog ini, sebaiknya dengan referensi dan tautan ke informasi lebih lanjut. Ini belum tentu merupakan teknologi terbaik yang tersedia atau *Best Available Technology* (BAT), namun lebih pada indikasi standar yang saat ini sedang dikerjakan.

Referensi
Semua deskripsi harus mempunyai referensi, yang tercantum dan ditegaskan dalam deskripsi kualitatif.

Deskripsi Kuatitatif

Untuk menganalisis secara komparatif antara teknologi yang berbeda, sangat penting bahwa data dapat dibandingkan secara nyata. Sebagai contoh, data ekonomi dinyatakan dalam tingkat harga yang sama dan pajak pertambahan nilai (PPN) atau pajak lainnya tidak termasuk. Alasannya adalah katalog teknologi itu harus mencerminkan biaya sosial ekonomi bagi masyarakat Indonesia. Dalam konteks ini, pajak tidak mewakili biaya aktual melainkan transfer modal antara pemangku kepentingan Indonesia, pengembang proyek dan pemerintah. Data penting diberikan untuk tahun yang sama. Tahun 2020 adalah basis untuk teknologi terkini, yaitu teknologi terbaik yang tersedia pada saat komisioning.

Semua biaya dinyatakan dalam dolar A.S. (USD), harga tahun 2016. Bila mengkonversi biaya dari X tahun ke USD2016, pendekatan berikut disarankan:

1. Jika biaya dinyatakan dalam IDR, konversikan ke USD dengan menggunakan kurs untuk tahun X (tabel pertama di bawah).
2. Kemudian ubah dari USD pada tahun X menjadi USD di tahun 2016 dengan menggunakan hubungan antara Indeks Harga Producer AS untuk "Manufaktur Peralatan Mesin, Turbin, dan Tenaga Transmisi" tahun X dan 2016 (tabel kedua di bawah).
3.

Kurs rata-rata tahunan
(sumber: MEMR, 2017, Handbook of energy & economic statistics of Indonesia)

Tahun	IDR ke USD
2007	9,419
2008	10,950
2009	9,400
2010	8,991
2011	9,068
2012	9,670
2013	12,189
2014	12,440
2015	13,795
2016	13,436

Indeks Harga Produser AS untuk manufaktur mesin, turbin, dan transmisi tenaga listrik. Industri ini terdiri dari perusahaan yang bergerak di bidang pembuatan turbin, peralatan transmisi tenaga, dan mesin pembakaran dalam (kecuali bensin dan pesawat terbang otomotif), "Sistem Klasifikasi Industri Amerika Utara, Amerika Serikat, 2017" hal. 258 dan Biro Statistik Tenaga Kerja AS, Nomor Seri: PCU333611333611)

Year	Producer Price Index
2007	168,9
2008	188,6
2009	209,9
2010	210,4
2011	212,5
2012	211,1
2013	215,0
2014	220,6
2015	221,1
2016	220,6

Waktu konstruksi, juga harus ditentukan dalam lembar data, yaitu waktu ketika pembiayaan terjamin, dan semua perizinan sudah selesai, dan waktu komisioning.

Berikut adalah data sheet yang khas, berisi semua parameter yang digunakan untuk menggambarkan teknologi tertentu. Data sheet terdiri dari bagian generik, yang identik untuk kelompok teknologi serupa (pembangkit listrik termal, pembangkit listrik tanpa panas dan teknologi pembangkit panas) dan bagian teknologi khusus, berisi informasi yang hanya relevan untuk teknologi tertentu. Bagian teknologi generik dibuat untuk memungkinkan perbandingan teknologi yang mudah.

Setiap sel di lembar data hanya boleh berisi satu nomor, yang merupakan perkiraan utama untuk teknologi khusus, yaitu tidak ada indikasi jangkauan. Ketidakpastian yang terkait dengan angka harus dinyatakan dalam kolom yang disebut ketidakpastian. Untuk menjaga agar lembar data tetap sederhana, tingkat ketidakpastian hanya ditentukan untuk tahun 2020 dan 2050. Tingkat ketidakpastian diilustrasikan dengan memberikan batas bawah dan lebih tinggi yang mengindikasikan interval kepercayaan 90%. Ketidakpastian itu terkait dengan teknologi 'standar pasar'; Dengan kata lain, interval ketidakpastian tidak mewakili rangkaian produk (misalnya produk dengan efisiensi lebih rendah dengan harga lebih rendah atau sebaliknya). Untuk teknologi khusus, katalog mencakup rangkaian produk, ini contohnya untuk tenaga batubara, di mana pembangkit tenaga kritis sub-kritis, super kritis dan ultra-super terwakili. Alasannya, untuk tenaga batubara hal tersebut tidak jelas, jenis produk mana yang menjadi standar pasar di Indonesia.

Tingkat ketidakpastian hanya perlu dinyatakan untuk angka paling kritis seperti misalnya biaya investasi dan efisiensi.

Semua data di lembar data direferensikan oleh nomor di kolom kanan paling kanan dan mengacu pada sumber yang ditentukan di bawah tabel.

Sebelum menggunakan data, perlu diketahui bahwa informasi penting dapat ditemukan di catatan di bawah tabel.

Bagian generik dari lembar data untuk pembangkit listrik termal, pembangkit listrik non termal dan teknologi pembangkitan panas disajikan di bawah ini:

Technology	**Name of technology**								
	2020	**2030**	**2050**	**Uncertainty (2020)**		**Uncertainty (2050)**		**Note**	**Ref**
Energy/technical data				**Lower**	**Upper**	**Lower**	**Upper**		
Generating capacity for one unit (MWe)									
Generating capacity for total power plant (MWe)									
Electricity efficiency, net (%), name plate									
Electricity efficiency, net (%), annual average									
Forced outage (%)									
Planned outage (weeks per year)									
Technical lifetime (years)									
Construction time (years)									
Space requirement (1000 m^2/MWe)									
Additional data for non thermal plants									
Capacity factor (%), theoretical									
Capacity factor (%), incl. outages									
Ramping configurations									
Ramping (% per minute)									
Minimum load (% of full load)									
Warm start-up time (hours)									
Cold start-up time (hours)									
Environment									
PM 2.5 (g per GJ fuel)									
SO_2 (degree of desulphuring, %)									
NO_X (g per GJ fuel)									
CH_4 (g per GJ fuel)									
N_2O (g per GJ fuel)									
Financial data									
Nominal investment (M$/MWe)									
- of which equipment									
- of which installation									
Fixed O&M ($/MWe/year)									
Variable O&M ($/MWh)									
Start-up costs ($/MWe/start-up)									
Technology specific data									

References:

1

2

Notes:

A

B

Energi/Data Teknis (*Energy/technical data*)

Kapasitas Pembangkitan (*Generating capacity*)

Kapasitas dinyatakan untuk baik mesin tunggal, mis. satu turbin angin atau mesin gas, maupun untuk pembangkit listrik total, misalnya pembangkit tenaga angin atau pembangkit listrik berbahan bakar gas yang terdiri dari beberapa mesin gas. Ukuran mesin dan total pembangkit listrik harus mewakili pembangkit listrik tertentu. Faktor-faktor untuk penskalaan data dalam katalog terhadap ukuran pembangkit lain selain yang telah disebutkan akan disajikan kemudian di bagian metodologi ini.

Kapasitas tersebut diberikan sebagai kapasitas pembangkitan netto dalam operasi yang kontinu, yaitu kapasitas kotor (output dari generator) dikurangi konsumsi sendiri (beban sendiri), sama dengan kapasitas yang dikirim ke grid.
Unit MW digunakan untuk kapasitas pembangkit listrik, sedangkan unit MJ/s digunakan untuk konsumsi bahan bakar.

Hal ini menggambarkan kisaran produk yang sesuai dalam kapasitas (MW), misalnya 200-1000 MW untuk pembangkit listrik tenaga batubara baru. Perlu ditekankan bahwa data dalam lembaran didasarkan pada kapasitas tertentu, misalnya 600 MW untuk pembangkit listrik tenaga batubara. Bila penyimpangan dari kapasitas tertentu dilakukan, dampak skala ekonomi perlu dipertimbangkan (lihat bagian tentang biaya investasi).

Efisiensi Energi (*Energy efficiencies*)
Efisiensi untuk semua pembangkit termal dinyatakan dalam persentase pada nilai panas kalor yang lebih rendah (nilai pemanasan yang lebih rendah atau nilai pemanasan bersih) pada kondisi sekitar di Indonesia, dengan mempertimbangkan suhu udara rata-rata sekitar 28°C.

Efisiensi listrik pembangkit listrik termal sama dengan total pengiriman listrik ke grid dibagi dengan konsumsi bahan bakar. Dua efisiensi dinyatakan: efisiensi label seperti yang dinyatakan oleh pemasok dan efisiensi tahunan yang diharapkan. Hal tersebut mungkin relevan untuk dijelaskan dalam catatan, bagaimana efisiensi tahunan bergantung pada pola operasi.

Seringkali terjadi bahwa efisiensi listrik sedikit menurun selama masa pengoperasian pembangkit listrik termal. Degradasi ini tidak tercermin dalam data yang disebutkan. Sebagai aturan praktis, kita dapat mengurangi 2,5 - 3,5% poin selama masa berlaku (misalnya dari 40% menjadi 37%).

Pemadaman Paksa dan Terencana (*Forced and planned outage*)
Pemadaman paksa didefinisikan sebagai jumlah jam kerja paksa tertimbang dibagi jumlah jam pemadaman paksa dan jam operasi. Jam kerja paksa tertimbang adalah jam yang disebabkan oleh pemadaman yang tidak direncanakan, dibobot sesuai dengan kapasitas yang ada.

Pemadaman paksa diberikan dalam persen, sementara pemadaman yang direncanakan (misalnya karena renovasi) diberikan dalam minggu per tahun.

Masa Pakai Teknis (*Technical Lifetime*)
Masa pakai teknis adalah waktu yang diharapkan dimana pembangkit energi dapat dioperasikan, atau mendekati spesifikasi aslinya, asalkan operasi dan perawatan normal berlangsung. Selama masa ini, beberapa parameter kinerja mungkin terdegradasi secara bertahap namun tetap berada dalam batas yang dapat diterima. Misalnya, efisiensi pembangkit listrik sering sedikit menurun (beberapa persen) selama bertahun-tahun, dan biaya operasi dan pemeliharaan meningkat karena keausan dan degradasi komponen dan sistem. Pada akhir masa pakai, frekuensi masalah operasional yang tidak terduga dan risiko kerusakan diperkirakan akan menyebabkan ketersediaan dan/atau biaya operasi dan pemeliharaan rendah yang tidak dapat diterima. Pada saat ini, pembangkit tersebut akan dinonaktifkan atau melewati masa pakai, yang menyiratkan renovasi besar komponen dan sistem yang diperlukan untuk membuat pembangkit sesuai untuk periode baru operasi lanjutan.

Masa pakai teknis yang tercantum dalam katalog ini adalah nilai teoretis yang melekat pada setiap teknologi, berdasarkan pengalaman. Dalam kehidupan nyata, pembangkit spesifik dari teknologi serupa dapat beroperasi untuk waktu yang lebih pendek atau lebih lama. Strategi untuk operasi dan pemeliharaan, mis. jumlah jam operasi, start up, dan reinvestasi yang dilakukan selama bertahun-tahun, akan sangat mempengaruhi umur sebenarnya.

Waktu Konstruksi (*Construction time*)
Waktu dari keputusan investasi akhir (FID) hingga komisioning selesai (*start of commercial operation*), dinyatakan dalam beberapa tahun

Persyaratan Ruang (*Space requirement*)
Jika relevan, kebutuhan ruang ditentukan (1000 m2 per MW). Persyaratan ruang antara lain dapat digunakan untuk menghitung sewa tanah, yang tidak termasuk dalam pembiayaan karena biaya tergantung pada lokasi tertentu dari pembangkit.

Kapasitas Rata-rata Tahunan (*Average annual capacity*)
Untuk teknologi pembangkit listrik non-termal ditampilkan faktor kapasitas tahunan rata-rata yang khas. Faktor kapasitas tahunan rata-rata merupakan rata-rata pembangkitan tahunan dibagi dengan pembangkitan netto tahunan teoritis, jika pembangkit tersebut beroperasi pada kapasitas penuh sepanjang tahun. Jam beban penuh setara per tahun ditentukan dengan mengalikan faktor kapasitas pada 8760 jam, jumlah jam dalam setahun.

Faktor kapasitas untuk teknologi seperti PLTS, angin dan tenaga air sangat spesifik. Dalam kasus ini, faktor kapasitas tertentu dilengkapi dengan informasi tambahan, misalnya peta atau tabel, menjelaskan bagaimana kapasitasnya akan bervariasi tergantung pada lokasi geografis pembangkit listrik. Informasi ini biasanya terintegrasi dalam deskripsi singkat teknologi

Faktor kapasitas teoritis merupakan realisasi produksi, dengan asumsi tidak ada pemadaman terencana atau paksa. Realisasi beban puncak mempertimbangkan pemadaman terencana dan paksa.

Konfigurasi Ramping (*Ramping configurations*)

The electricity ramping configuration of the technologies is described by five parameters:

E. Ramping (% per menit)
F. Beban minimum (persen dari beban penuh).
G. Waktu start up panas, (jam)
H. Waktu start up dingin, (jam)

Untuk beberapa teknologi, parameter ini tidak relevan, mis. Jika teknologinya bisa meluncur ke beban penuh seketika itu juga pada mode on/off

Parameter A adalah cadangan pemintalan (spinning reserve); yaitu kemampuan untuk naik dan turun saat teknologi sudah dalam pengoperasian.

Parameter B adalah beban minimum yang dapat dioperasikan boiler.

Parameter C, waktu start up panas, yang digunakan untuk teknologi boiler, didefinisikan sebagai waktu untuk memulai, dari titik awal dimana suhu air di evaporator berada di atas 100oC, yang berarti boiler dalam keadaan bertekanan.

Parameter D. Waktu start up dingin yang digunakan untuk teknologi boiler didefinisikan sebagai waktu yang dibutuhkan untuk mencapai suhu dan tekanan operasi dan mulai produksi dari suatu kondisi boiler pada suhu dan tekanan lingkungan.

Lingkungan (*Environment*)

Pembangkit harus dirancang untuk mengikuti peraturan yang saat ini berlaku di Indonesia dan direncanakan akan dilaksanakan dalam jangka waktu 2020.

Nilai emisi CO2 tidak disebutkan, namun hal ini dapat dihitung oleh pembaca katalog dengan menggabungkan data bahan bakar dengan data efisiensi teknologi.

Bila relevan, misalnya untuk turbin gas, emisi metana (CH4) dan Nitrous oxide (N2O), yang merupakan gas rumah kaca potensial, harus dinyatakan dalam gram per bahan bakar GJ

Emisi partikulat dinyatakan sebagai PM 2.5 dalam gram per bahan bakar GJ.
Emisi SOx dihitung berdasarkan kandungan belerang berikut dari bahan bakar:

	Batubara	Minyak	Gas	Gas Alam	Wood	Waste	Biogas
Sulphur (kg/GJ)	0.35	0.25	0.07	0.00	0.00	0.27	0.00

Kandungan Sulfur dapat bervariasi untuk berbagai jenis produk batubara. Kandungan Sulfur batubara dihitung dari kandungan belerang maksimum 0,8%. (Rich Coal Indonesia)
Bila digunakan peralatan teknologi desulfurisasi (biasanya pembangkit listrik besar), tingkat desulfurisasi dinyatakan dalam persentase.

Emisi NOx sama dengan NO2 + NO, dimana NO diubah menjadi NO2 dalam berat ekivalen. Emisi NOx juga dinyatakan dalam gram per bahan bakar GJ.

Data Keuangan (*Financial data*)

Data keuangan semua dalam harga tetap USD, tingkat harga 2016 dan tidak termasuk pajak pertambahan nilai (PPN) atau pajak lainnya.

Untuk proyeksi, biaya keuangan masa yang akan datang ada tiga pendekatan keseluruhan;
1) Dasar teknik bottom-up,
2) Delphi-survey, dan
3) Learning.

Katalog ini menggunakan pendekatan kurva belajar (learning curve) karena metode ini terbukti secara historis dan memungkinkan dalam memperkirakan laju pembelajaran pada kebanyakan teknologi. Analisis Energi Ea telah menyiapkan catatan tersendiri, Peramalan biaya teknologi produksi listrik berdasarkan pendekatan yang digunakan dalam katalog ini, dicantumkan dalam lampiran.

Biaya Investasi (*Investment costs*)
Biaya investasi atau biaya awal sering dilaporkan secara normal, mis. biaya per MW Biaya nominalnya adalah total biaya investasi dibagi dengan kapasitas pembangkit netto, yaitu kapasitas seperti yang terlihat dari grid.

Jika memungkinkan, biaya investasi harus dibagi menjadi biaya peralatan dan biaya pemasangan. Biaya peralatan meliputi pembangkit itu sendiri, termasuk fasilitas lingkungan, sedangkan biaya pemasangan mencakup bangunan, koneksi grid dan pemasangan peralatan.

Organisasi yang berbeda menggunakan sistem akun yang berbeda untuk menentukan elemen perkiraan biaya investasi. Karena tidak ada nomenklatur yang digunakan secara universal, biaya investasi tidak selalu mencakup barang yang sama. Sebenarnya, kebanyakan dokumen referensi tidak menyebutkan elemen biaya yang tepat, sehingga menimbulkan ketidakpastian yang tidak dapat dihindari yang mempengaruhi validitas perbandingan biaya. Selain itu, banyak penelitian gagal melaporkan tahun (tingkat harga) perkiraan biaya.

Dalam laporan ini, intensitas adalah biaya investasi yang mencakup semua peralatan fisik, yang biasanya disebut harga rekayasa, pengadaan dan konstruksi (EPC) atau biaya overnight. Biaya koneksi termasuk di dalamnya, namun penguatan tidak disertakan. Di sini diasumsikan bahwa koneksi ke jaringan berada dalam jarak yang masuk akal.

Sewa atau pembelian tanah tidak termasuk, namun dapat dinilai berdasarkan persyaratan ruang yang ditentukan berdasarkan data energi/teknis. Alasan tanah tidak secara langsung disertakan karena tanah sebagian besar tidak kehilangan nilainya dan dapat dijual kembali setelah pembangkit listrik memenuhi tujuannya dan telah dinonaktifkan

Biaya pra pengembangan pemilik (administrasi, konsultasi, manajemen proyek, persiapan lokasi, dan persetujuan oleh pihak berwenang) dan bunga selama konstruksi tidak termasuk. Biaya pembongkaran pembangkit dekomisioning juga tidak termasuk. Biaya dekomisioning dapat diimbangi dengan nilai sisa asset

Biaya Ekspansi Grid
Seperti yang disebutkan, biaya koneksi grid disertakan, namun mungkin biaya perluasan grid dari penambahan generator listrik baru ke grid tidak termasuk dalam data yang disajikan.

Siklus Bisnis
Biaya peralatan energi melonjak drastis pada 2007-2008. Kecenderungannya bersifat umum dan global. Salah satu contohnya adalah gabungan turbin gas siklus (CCGT): *"Setelah satu dekade berkisar antara $ 400 dan $ 600, sebuah kW memasang harga EPC untuk CCGT meningkat tajam pada tahun 2007 dan 2008 menjadi puncaknya sekitar $ 1250 / kW pada Q3: 2008. Puncak ini mencerminkan harga tender: tidak ada transaksi aktual yang dilakukan pada harga ini. Harga sudah turun, dengan harga sekarang sekitar $ 1050 / kW "*(Global CCS Institute). Variasi yang belum pernah terjadi sebelumnya jelas menyulitkan data benchmark dari tahun-tahun belakangan ini, namun katalog saat ini tidak dapat diproduksi tanpa menggunakan sejumlah sumber yang berbeda dari tahun yang berbeda. Pembaca terpaksa harus memperhatikan hal ini, saat membandingkan biaya teknologi yang berbeda.

Skala Ekonomi
Biaya per unit pembangkit listrik yang lebih besar biasanya kurang dari pada pembanghkit yang lebih kecil. Ini disebut 'skala ekonomi'. Proporsionalitas diuraikan secara terperinci dalam artikel “Economy of Scale in Power Plants”pada edisi Agustus 1977 dari Majalah Power Engineering (halaman 51). Persamaan dasarnya adalah:

$$\frac{C_1}{C_2} = \left(\frac{P_1}{P_2}\right)^a$$

Where: C_1 = Biaya investasi pembangkit 1 (misalnya dalam jutaan US $)

C_2 = Biaya investasi pembangkit 2
P_1 = Kapasitas pembangkit 1 (misalnya di MW)
P_2 = Kapasitas pembangkit 2
a = Faktor proporsionalitas

Selama bertahun-tahun, faktor proporsionalitas rata-rata sekitar 0,6, namun perpanjangan waktu proyek dapat menyebabkan faktor tersebut meningkat. Namun, bila digunakan dengan hati-hati, rumusan ini dapat diterapkan untuk mengubah data dalam katalog ini ke ukuran pembangkit lain yang belum disebutkan dalam katalog ini. Perlu diketahui bahwa pembangkit pada dasarnya identik dalam teknik konstruksi, desain, dan kerangka waktu dan bahwa satu-satunya perbedaan yang signifikan adalah ukuran.
Untuk pembangkit berskala besar, seperti pembangkit listrik tenaga batubara besar, kita mungkin telah mencapai batas praktis, karena sangat sedikit investor yang bersedia menambahkan penambahan 1000 MW atau lebih. Sebagai gantinya, dengan membangun beberapa unit di tempat yang sama dapat memberikan penghematan yang cukup dengan membiarkan pembagian keseimbangan peralatan pabrik dan infrastruktur pendukung. Biasanya, sekitar 15% penghematan biaya investasi per MW dapat dicapai untuk siklus gabungan gas dan pembangkit listrik tenaga uap yang besar dari pengaturan satuan ganda versus satu unit ("Proyeksi Biaya Pembangkit Listrik", IEA, 2010). Data keuangan dalam katalog ini semuanya untuk pembangkit unit tunggal (kecuali untuk peternakan angin dan solar PV), jadi orang dapat mengurangi 15% dari biaya investasi, jika pembangkit sangat besar dipertimbangkan.
Kalau tidak ada aturan lain, pembaca katalog dapat menerapkan faktor proporsionalitas 0,6 untuk menentukan biaya investasi pembangkit dengan kapasitas yang lebih tinggi atau lebih rendah daripada kapasitas yang ditentukan untuk teknologi. Kisaran produk (kapasitas) yang relevan ditentukan untuk setiap teknologi.

Biaya Operasi dan Pemeliharaan (*O&M costs*)
Bagian tetap O & M dihitung sebagai biaya per kapasitas pembangkit per tahun ($ / MW / tahun), di mana kapasitas pembangkitnya adalah yang ditentukan pada awal bab ini dan dinyatakan dalam tabel. Ini mencakup semua biaya, terlepas dari berapa jam pembangkit dioperasikan, mis. administrasi, staf operasional, pembayaran untuk perjanjian layanan O & M, biaya jaringan atau sistem, pajak properti, dan asuransi. Investasi ulang yang diperlukan agar pembangkit tetap beroperasi dalam masa berlaku teknis juga disertakan, sedangkan reinvestasi untuk memperpanjang umur di luar masa pakai teknis tidak termasuk. Reinvestasi didiskon dengan tingkat diskonto tahunan 4% secara riil. Biaya reinvestasi untuk memperpanjang umur pembangkit dapat dicantumkan dalam catatan jika data tersedia.

Biaya variabel O & M ($ / MWh) mencakup konsumsi bahan pendukung (air, pelumas, aditif bahan bakar), perawatan dan pembuangan residu, suku cadang dan perbaikan dan pemeliharaan terkait (namun bukan biaya yang dijamin oleh jaminan dan asuransi). Biaya pemeliharaan terencana dan tidak terencana dapat jatuh di bawah biaya tetap (misalnya jadwal kerja pemeliharaan tahunan) atau biaya variabel (misal: bekerja tergantung pada waktu operasi sebenarnya), dan dibagi sesuai dengan itu.

Biaya bahan bakar tidak termasuk.

Perlu diperhatikan bahwa biaya O & M sering berkembang seiring berjalannya waktu. Biaya O & M yang dinyatakan adalah biaya rata-rata selama masa pakai pembangkit

APPENDIX: FORECASTING COST OF ELECTRICITY PRODUCTION TECHNOLOGIES

Historic data shows that the cost of most electricity production technologies have been reduced over time. It can be expected that further cost reductions and improvements of performance will also be realized in the future. Such trends are important to consider for future energy planning and therefore need to be taken into account in the technology catalogue.

Three different approaches to forecasting are often applied:

1. **Engineering bottom-up assessment.** Detailed bottom-up assessment of how technology costs may be reduced through concrete measures, such as new materials, larger-scale fabrication, smarter manufacturing, module production etc.
2. **Delphi-survey**. Survey among a very large group of international experts, exploring how they see costs developing and the major drivers for cost-reduction.
3. **Learning curves.** Projection based on historic trends in cost reductions combined with estimates of future deployment of the technology. Learning curves expresses the idea that each time a unit of a particular technology is produced, some learning accumulates which leads to cheaper production of the next unit of that technology.

Each of the three approaches contain advantages and disadvantages.

	Advantages	**Disadvantages**
Engineering bottom-up	• Gives a good understanding of underlying cost-drivers. • Provides insight to how costs may be reduced.	• Requires information at a very detailed level. • Difficult to obtain objective (non-biased) information from the experts, who possess the best knowledge of a technology. • Potentially very time consuming.
Delphi-survey	• Input from a large number of experts improves robustness of forecast.	• Costly to carry out survey. • Challenge to identify relevant and unbiased experts.
Learning curves	• Large number of studies have examined learning rates and documented that learning rates correlations are real. • The over-arching logic of learning rates has proved correct for many technologies and sectors. • Data available to perform learning curves for most important technologies.	• Does not explain why cost reductions take place. • The theory assumes that each technology makes up an independent technology complex, but in practice there may be a significant overlap between different technologies, which makes the interpretation and use of learning curves more complicated.

Advantages and disadvantages of different methodologies for forecasting technology costs.

For the purpose of the present project, the learning curve approach is the most suitable way forward. Firstly, the learning curve correlations are well documented, secondly, the risk of bias is reduced compared to the alternative approaches, thirdly, it does not involve costly and time-consuming surveys.

The results from the learning curves will be compared by projections from international literature references.

Learning curve based cost projections are dependent on two key inputs: a projection of the demand of the technologies and estimated learning rate. Essentially, only this limited information is required to perform the cost projection.

Global demand for technologies
To estimate the future demand of each of the technologies we rely on analyses of the future global electricity supply from the International Energy Agency. How the global demand and composition of electricity will develop is off course associated with a high level of uncertainty related to climate policy ambitions, costs and availability of fossil fuel resources and the development of existing and new electricity generation technologies.

In its Energy Technology Perspectives reports', the IEA set out two global pathways, the 2 DS scenario and the 4 DS scenario, with varying degree of climate policy commitment:

"The 2°C Scenario (2DS) has the main focus of Energy Technology Perspectives. The 2DS lays out an energy system deployment pathway and an emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C.

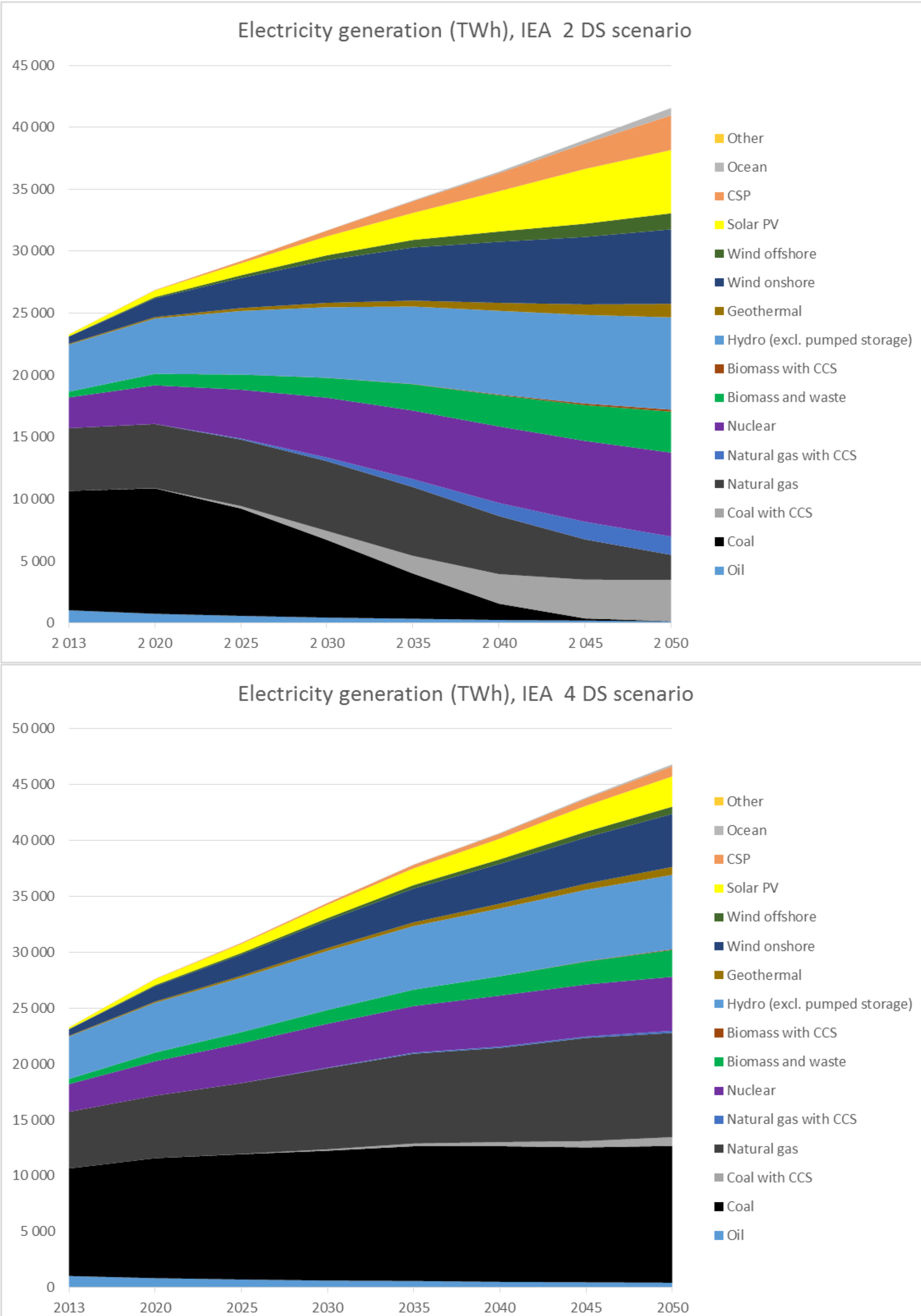
The 4°C Scenario (4DS) takes into account recent pledges by countries to limit emissions and improve energy efficiency, which help limit the long-term temperature increase to 4°C." [1]

We use the two IEA scenarios to set a realistic framework for the future technology deployment.

Both scenarios project approximately a doubling in global electricity demand between today and 2050. In the 2DS scenarios wind and solar power and other fluctuating renewable energy technologies are expected to account for close to 40% of global electricity generation by 2050. The scenarios also see a stronger role for nuclear power whereas coal fired power plants are either phased out or replaced or refitted with CCS technology.

The 4DS scenario on the other hand still sees a large role for coal power with generation increasing by close to 30% compared to today, whereas gas fired generation is close to being doubled. Wind and solar demonstrate very large increases but their combined share of total power generation is still only 20% by 2050.

[1] https://www.iea.org/publications/scenariosandprojections/ , visited 12-06-2017



Electricity supply in the IEA's 2 and 4 DS scenarios. IEA – Energy Technology Perspectives 2016.

Looking at the installed generation capacities, the changes in power plant composition is more striking. The following tables show how the accumulated capacities of different electricity generation technologies develop toward 2050, using 2020 as the starting point (=1). The accumulated figures represent total installations, taking into consideration the need for replacement of worn out power plants over the period. In the 4DS scenario, for example, the accumulated coal fired capacity is increased by 70% by 2050 compared to 2020, whereas accumulated solar PV capacity is five-doubled over the same time horizon.

Accumulated generation capacities relative to 2020, in the 4 DS scenario. The accumulated figures represent total installations, taking into consideration the need for replacement of worn out power plants over the period.

Accumulated generation capacity relative to 2020 (=1)	**2030**	**2040**	**2050**
Oil	1	1	1.3
Coal	1.3	1.5	1.7
Natural gas	1.4	1.9	2.4
Nuclear	1.4	1.7	1.9
Biomass and waste	1.5	2	2.7
Hydro (excl. pumped storage)	1.2	1.5	1.7
Geothermal	2	3.5	5.7
Wind onshore	1.9	2.8	4.3
Wind offshore	2	3.5	6.2
Solar PV	2.2	3.3	5.1
CSP	4.7	13.3	24.4
Ocean	7.7	25.6	77.8

In the 2DS scenario the accumulated coal fired capacity only sees a 10% increase between 2020 and 2050, whereas off-shore wind is 11-doubled and solar PV capacity more than 8-doubled.

Accumulated generation capacities relative to 2020, in the 2 DS scenario.

Accumulated generation capacity relative to 2020 (=1)	2030	2040	2050
Oil	1	1	1.1
Coal	1.1	1.1	1.1
Coal with CCS	52.6	166.2	262.7
Natural gas	1.2	1.4	1.6
Natural gas with CCS	31	107.7	178.1
Nuclear	1.6	2.1	2.5
Biomass and waste	1.7	2.6	3.5
Biomass with CCS	16.2	105.9	381.2
Hydro (excl. pumped storage)	1.3	1.7	1.9
Geothermal	2.6	4.9	8.3
Wind onshore	2.3	3.4	5
Wind offshore	3.3	6.5	11.3
Solar PV	2.7	5.4	8.5
CSP	12.2	33.2	61.6
Ocean	10	57.5	275.4

Learning rates

Learning rates typically vary between 5 and 25%. In 2015, Rubin et al published “A review of learning rates for electricity supply technologies”, which provides a comprehensive and up to date overview of learning rates for a range of relevant technologies:

Technology	**Mean learning rate**	**Range of studies**
Coal	8.3%	5.6 to 12%
Natural gas CC	14%	-11 to 34%
Natural gas, gas turbine	15%	10 to 22%
Nuclear	-	Negative to 6%
Wind, onshore	12%	-11 to 32%
Wind, offshore	12%	5 to 19%
Solar PV (modules)	23%	10 to 47%
Biomass power	11%	0 to 24%
Geothermal	-	-
Hydroelectric	1.4%	1.4% (one study)

Learning rates for different technologies (Source: Rubin et al., 2015)

The authors of the review emphasize that “methods, data, and assumptions adopted by researchers to characterize historical learning rates of power plant technologies vary widely, resulting in high variability across studies. Nor are historical trends a guarantee of future behaviour, especially when future conditions may differ significantly from those of the past.”.

Still, the study gives an indication of the level of learning rates, which may be expected. 10-15% seems to be a common level for many technologies. PV shows a higher level, whereas, nuclear power and coal are in the lower end. The low learning rates of nuclear and coal power may be a result of increasing external requirements, in the shape of higher safety standards for nuclear power and emission norms for coal power, adding to investment costs.

Considering the uncertainties related to the estimation of learning rates a default learning rate of 12.5% is applied for all technologies expect solar PV modules, where a learning rate of 20% is deemed to be more probable in view of the high historic rates. When the abovementioned learning rates are combined with the future deployment of the technologies projected in the IEA scenarios, an estimate of the cost development over time can be deduced.

Technology cost compared to 2020 (2020 = 100%)		**2DS**		**4 DS**		**Average of 2 & 4 DS**	
Technology	**Learning rate**	**2030**	**2050**	**2030**	**2050**	**2030**	**2050**
Oil	12.50%	100%	99%	100%	95%	100%	97%
Coal	12.50%	99%	99%	96%	90%	97%	94%
Coal with CCS	12.50%	47%	34%	NA	NA	NA	NA
Natural gas	12.50%	96%	92%	94%	85%	95%	88%
Natural gas with CCS	12.50%	52%	37%	NA	NA	NA	NA
Nuclear	12.50%	91%	84%	94%	88%	93%	86%
Biomass and waste	12.50%	91%	78%	93%	82%	92%	80%

Biomass with CCS	12.50%	58%	32%	NA	NA	NA	NA
Hydro	12.50%	95%	88%	96%	90%	95%	89%
Geothermal	12.50%	83%	67%	87%	72%	85%	69%
Wind onshore	12.50%	85%	73%	88%	75%	87%	74%
Wind offshore	12.50%	80%	63%	87%	70%	83%	67%
Solar PV modules	20.00%	72%	50%	78%	59%	75%	55%
CSP (concentrated solar power)	12.50%	62%	45%	74%	54%	68%	50%
Ocean	12.50%	64%	34%	68%	43%	66%	39%
*Thermal boiler/steam turbine**	12.50%	*97%*	*92%*	*96%*	*89%*	*96%*	*91%*
*Gas turbines***	12.50%	*96%*	*91%*	*94%*	*85%*	*95%*	*88%*
*CCS component****	12.50%	*48%*	*35%*	*NA*	*NA*	*NA*	*NA*

*Estimated technology cost in the IEA's 2 and 4 DS scenarios in 2030 and 2050 (IEA, Energy technology perspectives 2016) relative to 2020. * Coal, Coal CCS, biomass/waste, biomass waste/CCS. ** Gas and gas CCS, *** Coal CCS, gas CCS, biomass CCS.*

For all thermal technologies (except CCS), i.e. oil, coal natural gas, nuclear and biomass power, moderate cost decreases are projected, up to around 20% by 2050. The main reason for this is the extensive historic deployment of the thermal technologies, which means that their relative growth is moderate. Solar PV, CSP and ocean technologies are expected to see the strongest cost reductions. For solar PV, this is also due to the higher anticipated learning rate (20%) compared to the other technologies (12.5%). In this respect, it should be mentioned that the projection for CSP and particularly ocean technologies is associated with particularly high uncertainty, due to the limited application of these power generation technologies today.

Wind onshore is already widely deployed, and hence, the projected cost development is also moderate, a reduction of approximately 25% is projected by 2050. For offshore wind is expected to see a larger amount of doublings leading to cost reductions around 35%. It should be mentioned, that almost all the learning curve studies for wind power, referenced by Rubin et al. focus only on the development of the capital cost of the wind turbines ($ per MW). At the same time, focus from manufacturers have been dedicated to increasing the capacity of wind turbines (higher full load hours per MW) and therefore the effective cost reduction expressed as levelized cost of electricity generation, is likely to be higher. This trend is likely to prevail in the future.

Some technologies have a number of common core components. For example coal and biomass fired power plants with and without CCS technology, plants apply a boiler and steam turbine. This implies that learning effects from the deployment of for example biomass fired power plants will have a spill-over effect on coal-fired power plants and vice versa. Similarly the CCS technology itself can be applied on coal, gas or biomass fired power plants. The figures in *italic*, show the projected cost for specific components by looking at the combined effect of several groups of technologies.

Global and regional learning

The learning effects found in this review express a global view on technology learning. Considering that the majority of technology providers today are global players this seems to be a reasonable assumption. Therefore, cost reductions generated in one part of the world will easily spread to the other regions.

Still, in a 2020 perspective Indonesian prices of some technologies may be higher (or in some cases lower) than international reference values because local expertise is limited. However, as Indonesian know-how is built up and technologies are adapted to the Indonesian context within the next decade, it is reasonable to assume that cost will approach the international level.

References

IEA, 2016, Energy Technology Perspectives 2016. IEA/OECD.

Edward S. Rubin, Inês M.L. Azevedo, Paulina Jaramillo, Sonia Yeh. Review article. A review of learning rates for electricity supply technologies. Elsevier 2015.