SEAS
Sustainable Energy Association of Singapore

A case for sustainability:

Accelerating the adoption of Renewable Energy in Singapore

A White Paper by the

Clean Energy Committee of the

Sustainable Energy Association of Singapore

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Contents

EXECUTIVE SUMMARY

This White Paper explains how Renewable Energy (RE) sources can generate about **3'635 GWh of electricity each year, or approximately 7.3% of Singapore's forecast 2025 demand, with no government subsidies** (compared to <1% today).

There is also scope for significant penetration of renewable energy beyond 10% after 2025. Solar Photovoltaics (PV) will generate 2'400 GWh/year or 4.8% of 2025 forecasted demand; biogas will cover 350 GWh or 0.7%, and biomass 785 GWh/year or 1.6% of 2025 forecasted demand. A token amount of wind and tidal power contribute the balance 0.2%.

Renewable energy is an alternative source of energy that will improve Singapore's energy diversity, thereby improving its energy security and reducing its dependence on imported fuel. Increasing the adoption of RE will support Singapore's unconditional pledge to reduce greenhouse gas emissions by 2020 to 7-11 per cent below Business As Usual (BAU) levels, and position Singapore as a hub for regional low carbon growth.

This Paper outlines the business case for solar, biomass and biogas, and advances practicable solutions from an industry perspective for removing the existing barriers to increase the adoption of such RE sources.

Generally, the price of renewable energy has fallen due to the reduction of raw material costs. Based on current system cost in Singapore, the LCOE for solar PV electricity is around SGD0.15/kWh and the cost for biomass and bio-gas is SGD0.19/kWh whereas current retail tariffs for non-contestable customers are SGD0.26/kWh. This White Paper dispels the myth that renewable energy is expensive – it is very much competitive against existing electricity prices in Singapore.

There are regulatory, commercial, and technical barriers to accelerating renewable energy in Singapore. Firstly, there are restrictions on feeding renewable energy generation directly into the grid. The Energy Market Company (EMC), which operates and administers Singapore's wholesale electricity market, currently has no energy trading tool that allows for the ready sale of renewable energy. Secondly, contestable customers are not able to sell excess RE to the grid (although we note that the Energy Market Authority (EMA) Consultation Paper released 28 October 2013 is addressing both these points). Thirdly, waste is not segregated in Singapore. NEA has implemented a policy of restricting wood and horticulture waste disposal to the public incinerator, which is some form of separation. But sufficient amounts of pure homogeneous food waste (by far the largest amount of digestible organic waste in Singapore) are still difficult to obtain. Lastly, there is also the challenge of intermittency in the case of solar.

Once these barriers are removed, there is up to SGD 4 billion in private sector investment waiting to be unlocked over the next 12 years. EMA has already taken the first step by raising its Intermittent Generation Threshold (IGT) from 350MW to 600MW. Since solar and wind energy are intermittent sources of renewable energy (RE), the higher IGT will allow more RE to connect to the grid. With the right approach, renewable energy will increase its contribution from less than 1% of demand in 2013, to more than 7% by 2025. Singapore can also export these solutions, positioning itself as a leader in the region for urban renewable energy turnkey system supply, operation, financing and consulting.

1. CURRENT SITUATION

1.1 Electricity generation and consumption in Singapore

Stable and reliable electricity supply is a fundamental resource behind Singapore's economic success. Without reliable 24x7 electricity supply, the country would not be able to attract foreign as well as local investments into its high technology manufacturing and services base, providing one of the highest living standards in the world today.

Singapore's electricity demand has grown 4.5 times from 1986 to 2012.

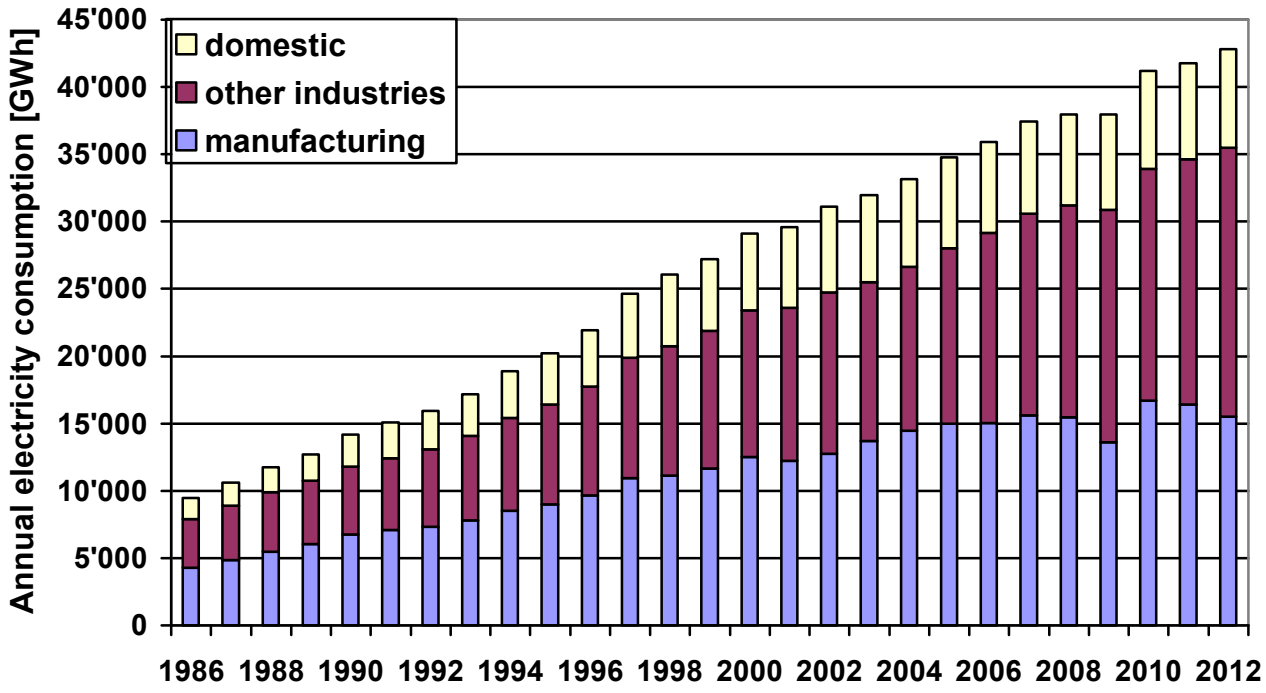


Fig 1 Singapore's yearly electricity consumption (Source: Singapore Yearbook of Statistics)

Under Singapore's current centralised generation infrastructure, electricity is mainly produced at large generation facilities with individual name-plate rating in the hundreds of MW, and transmitted though the national grid to end consumers.

Today, all but one of Singapore's power plants are located in the western region of Singapore. Albeit with a high demand centre from the industrial estates and petrochemical complexes, the power system in the west faces security constraints that limit the maximum amount of power that can be exported. This is being addressed by the construction of a new 400kV substation.

Optimal land utilisation has always been a cornerstone of urban planning in Singapore, hence the recent efforts to distribute new industrial estates to the east, such as the aerospace hub. With increasing power demand from commercial buildings and industrial hubs that account for more than 80% of demand, the challenge is to supply power as efficiently as possible to demand centres.

According to the Singapore Energy Statistics 2013 published by the Energy Market Authority (EMA), Singapore's fuel mix for electricity generation was dominated by natural gas (84.3%), followed by petroleum products (12.3%). Other energy products such as solar and waste (municipal waste and biogas) constituted the residual 3.4% of resources consumed.

Unit: ktoe

2012	Petroleum Products	Natural Gas	Others	Electricity
Total Electricity Generation	**-1,335.7**	**-7,485.2**	**-886.1**	**4,034.0**
Main Power Producers	-1,278.2	-7,110. 4	-602.3	3,886.4
Autoproducers	-57.5	-374.8	-283.8	147.6

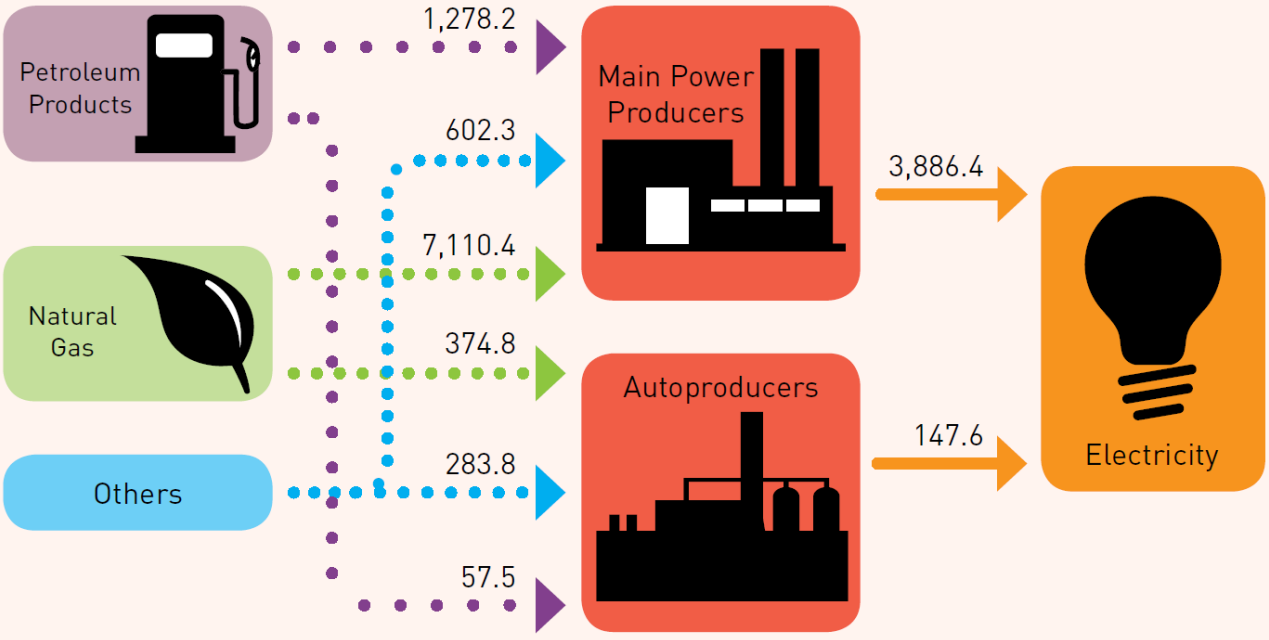


Fig 2 Energy transformation from primary energy to electricity
Source: Singapore Energy Statistics 2013 (EMA)

Singapore's electricity market is split between two types of customers: non-contestable and contestable (see **Fig 3**). The former currently account for one third of total demand and are mostly households and small commercial consumers. They have no choice of supplier, and are served by SP Services at flat, regulated tariffs that are reviewed quarterly.

Contestable customers currently comprise two thirds of the total and can buy directly from the central pool at prices that vary every half hour, or select from a number of electricity retailers who offer fixed rate or variable rate contracts.

In October 2013, EMA announced upcoming revisions that will open up contestability to a wider range of customers. The current threshold for contestability is 10'000kWh/month. This will drop to 8'000 from April 2014 and again to 4'000kWh/month from October 2014.

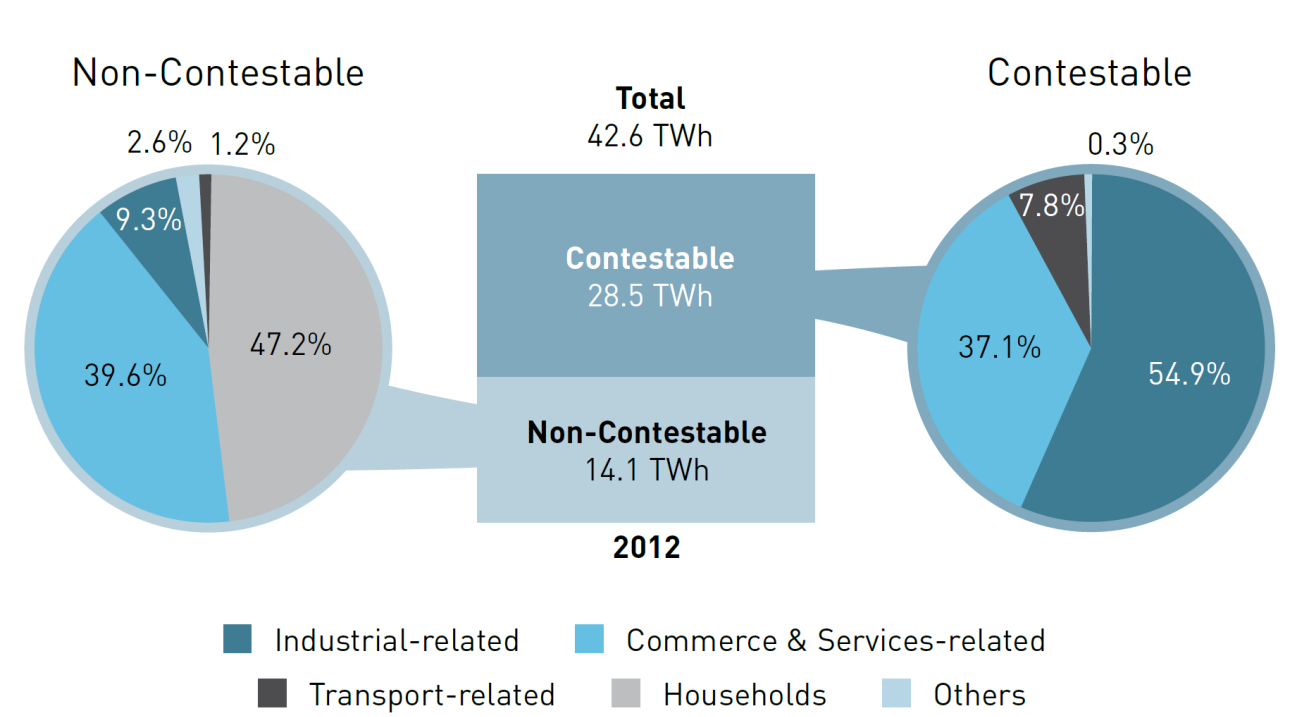


Fig 3 Electricity sales by contestability & sector (EMA: Singapore energy Statistics 2013)

2. THE CASE FOR RENEWABLE ENERGY (RE)

This White Paper conservatively forecasts the **annual production of 3'635GWh** of electricity from renewable energy sources by the year 2025.

2.1 The benefits of RE

Renewable energy (RE) includes solar, wind, hydro-electric and tidal power as well as geothermal energy, biofuels and biomass. In Singapore, the most viable sources of RE are currently solar, biomass and biogas. The deployment of RE will bring extensive economic, environmental and social benefits to Singapore as set out below.

2.1.1 Commercial viability

Renewable Energy is cost-effective against conventional energy in Singapore without government subsidies. The falling price of green technology and the accumulated system installation experience have made RE economically viable. This Paper will specifically address the financial viability of solar PV, biogas and biomass in Singapore.

2.1.2 Reducing CO_2 emissions

Displacing more conventional energy with renewable energy will enable Singapore to cut greenhouse emissions.

3'635GWh/yr of clean electricity from RE sources will mitigate 1.74 million metric tonnes of CO_2 per year. This is based on Singapore's Electricity Grid Emission Factor[1] of approximately 0.5 tonnes of CO_2 per MWh generated by our fossil fuel power plants.

Singapore has pledged to reduce its emissions to 16% below the 2020 business-as-usual (BAU) level if there is a legally binding global agreement in which all countries implement their commitments in good faith. Singapore has also started to implement mitigation and energy efficiency measures, to unconditionally reduce its emissions by 7% to 11% below 2020 BAU level. A focused approach to increasing the deployment of RE will certainly support Singapore's aspirations to reduce emissions.

A widespread adoption of RE solutions will also position Singapore favourably as a hub for carbon management and test-bedding as ASEAN moves to mitigate climate change. RE can also be a means to bridge economic ties between Singapore and its neighbouring countries through joint projects and by sharing technological know-how.

2.1.3 Security of energy supply

For energy security it is essential to have a diversified mix of energy generation technologies rather than relying on the imported standard 80:20 mix of fossil gas and fuel oil. Displacing more conventional energy with RE will enable Singapore to depend less on imported fuel. Singapore should maximise the percentage of energy it can generate based on economically viable alternative energy solutions.

2.1.4 Shifting towards a low carbon economy

Global demand for electricity will rise by 80% by 2040[2], and 90% of that will originate from countries with fast developing economies like Singapore, a country currently largely dependent on imported fossil fuels. Many countries envisage a gradual shift from traditional fossil fuels to cleaner and sustainable energy alternatives to secure their growing energy demand. Singapore cannot afford to ignore or deviate from the low carbon path.

2.1.5 Singapore as a clean energy hub

Creating a sustainable green economy means building up industrial capacity within the entire supply chain. This leads to research and innovation, enhancing labour skills and education levels in the workforce.

[1] Average Operating Margin (OM) in 2012 = 0.4977kg of CO_2/kWh, based on UNFCCC Clean Development Mechanism tool to calculate emission factors in an electricity system. Data from EMA.

[2] Exxon Report 2012

Designing, constructing, operating and maintaining RE power plants creates many direct local jobs throughout the value chain. The sector also creates high-level indirect jobs in R&D, consulting and financing.

Increases in RE will strengthen clean tech/renewable energy clusters in Singapore and build further domestic business and investment flows. Singapore is already a testing ground for the commercialisation of innovative renewable energy solutions adapted to the tropics. But Singapore is also the first natural (unsubsidised) market in the ASEAN region, giving the country a head start with exportable expertise to the wider ASEAN region, positioning Singapore as a hub for renewable energy.

2.2 The scale and potential of RE in Singapore

With a multi-faceted approach to accelerate the adoption of RE in Singapore, RE sources can generate about **3'635 GWh of electricity each year, or approximately 7.3% of Singapore's forecast 2025 demand**, with no government subsidies (compared to <1% today). There is also scope for significant penetration of renewable energy beyond 10% after 2025.

In this conservative and realistic scenario, solar PV will generate 2'400 GWh/year or 4.8% of 2025 forecasted demand; biogas will cover 350 GWh or 0.7%, and biomass 785 GWh/year or 1.6% of the 2025 forecasted demand.

Higher levels subsequently (i.e. to 2050) are technically feasible. It is possible to decarbonise electricity generation by lowering technical, commercial and regulatory barriers, and by encouraging near-to-market and cost-effective technologies, such as solar photovoltaics and biomass tri-generation systems.

The table below summarises the forecast contribution of each RE technology.

Source	Capacity [MW]	Energy by 2025 [GWh/yr]	Share of 2025 demand
PV	2'000	2'400	4.8%
Biogas*	50	350	0.7%
Biomass*	80	785	1.6%
Wind	50	80	0.2%
Tidal	10	20	0.0%
Total		3'635	7.3%

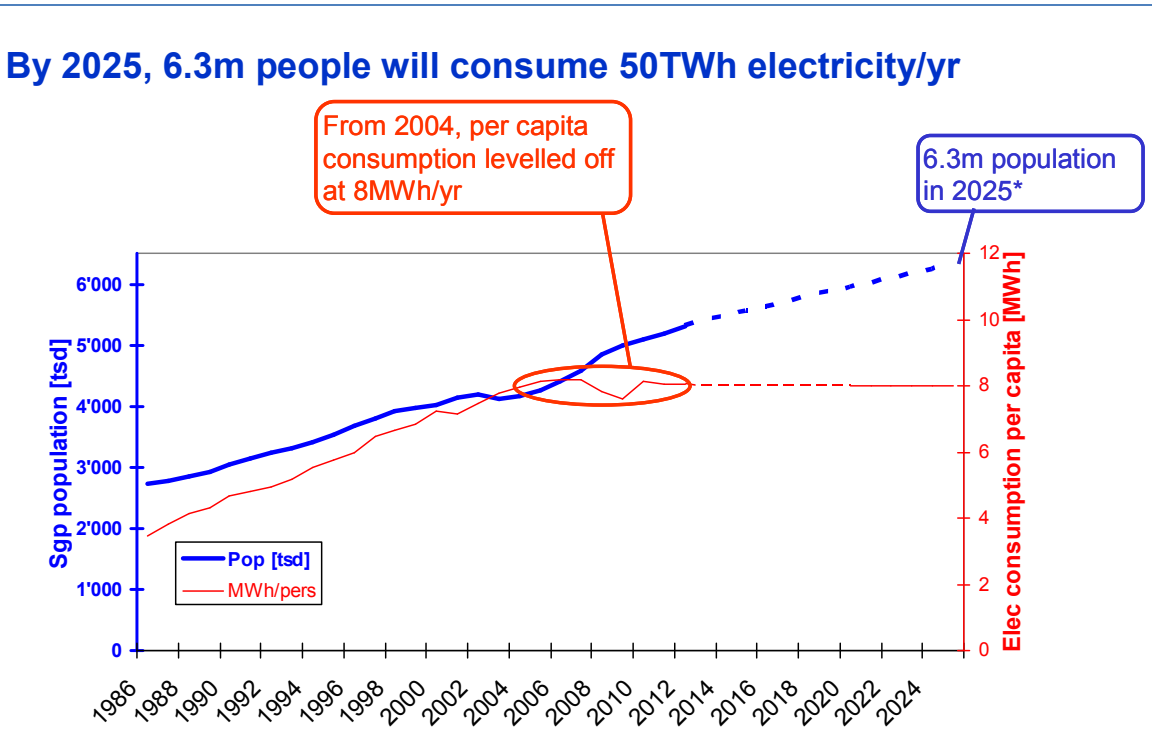
Table 1: Forecast RE capacities and contributions by 2025. Source: industry analysis

*Biomass and Biogas: excludes the 4 units of MSW[3] incineration plants in Singapore.

2.2.1 Forecasting electricity demand in 2025

Until 2004, demand for electricity in Singapore grew rapidly as its population and industrial production grew. However, since 2004, the *demand per capita* has remained rather constant at around 8 MWh per year, meaning that overall demand since 2004 grew only in direct proportion to population growth. This levelling off of per capita demand could be due to a combination of the wealth effect (saturation of demand for appliances like air conditioners and white goods) and increased attention to energy efficiency (promoted by government initiatives such as BCA's Green Mark scheme). We anticipate this consistent level of demand per capita to remain the same, barring any structural changes in the market. By 2025, an estimated 6.3 million people in Singapore will therefore be projected to consume 50TWh electricity per year (see **Fig 4**).

[3] MSW = Municipal Solid Waste



* Based on 5.8 – 6.0m by 2020 and 6.5 – 6.9m by 2030, in Population White Paper by National Population & Talent Division, PMO, Jan 2013. Population & electricity consumption data: www.singstat.gov.sg

Fig 4 The correlation between forecasted population and electricity demand

It is always hard to correctly predict electricity demand over a decade into the future, and many past predictions have turned out to be wrong. Several modifiers can drive demand above or below these predictions:

Factors that will increase demand	Factors that will decrease demand
New high-intensity energy users such as petrochemical plants and data centres	Improvements in energy efficiency, both in industry as well as in buildings. BCA's Green Mark initiative and NEA + SPRING Singapore are successfully promoting energy efficiency
Increase in public transport (MRT and LRT are powered by electricity), which shift energy demand from primary fossil fuel to electricity	District cooling, which reduces the energy needed for communities and clusters to air condition their premises, compared to using individual HVAC equipment
Rapid growth of electric vehicles (EVs) and hybrids displacing conventional combustion engine vehicles	Demand Response mechanisms that motivate consumers to manage their electricity consumption better and cut down unnecessary use, by quantifying the cost of wasteful consumption

2.3 Key enablers

A number of key framework conditions/enablers need to be in place to increase RE deployment and penetration in Singapore: **cost competitiveness, distributed generation, system integration, market mechanisms for the sale of renewable electricity and policy frameworks**.

In the following two sections of this White Paper (3 & 4), we set out the business case for solar PV, biomass and biogas technologies, with a detailed analysis of their cost competitiveness or economic viability. In the last section (5: "Moving forward") we assess the remaining key enabling factors/conditions to enhance the adoption of (and investment in) such renewable energy technologies and key stakeholders involved.

3. THE BUSINESS CASE FOR SOLAR PV

In this section we set our analysis of cost competitiveness or economic viability of Solar PV in the Singapore context.

3.1 The solar PV opportunity in Singapore

Solar PV is a natural choice for Singapore. Thanks to its position very close to the Equator, the country has high solar irradiation levels with minimal seasonal variation.

Despite scarcity of land, **Singapore has enough space to accommodate 6GWp[4] of solar PV**, which can generate 7.2TWh of electricity each year, or approximately 17% of Singapore's current electricity demand.

Space type	Area used	Total area [m²]	Area utilisation factor	Net-usable area [m²]	Estimated mid term usage	Estimated usage 2025-2030
Roof-top	HDB blocks	14'000'000	0.48	6'700'000	100%	100%
	Other buildings	42'000'000	0.65	27'300'000	100%	100%
Façades	Top-5 stories	40'000'000	0.4	16'000'000	0%	100%
Infrastructure	MRT tracks	390'000	1	400'000	100%	100%
Islets	Ground-mounted	50'000'000	0.20	10'000'000	25%	100%
Inland waters	Floating PV (mainland only)	20'000'000	0.25	5'000'000	40%	100%
TOTAL				65'400'000	40 km²	65 km²

Table 2: Available space for PV installations in Singapore (Source: SERIS[5])

The capacity of 6GWp is based on installing approximately 100Wp/m² of PV on 60-65km² of available space.

For various reasons, not all accessible space will be tapped. Even if it makes good commercial sense to install PV on a rooftop, not every building owner will choose to do so. Façades might prove too expensive for practical installation. As land cost is at a premium in Singapore, large solar farms might not receive approval for installation, whether on the mainland or on islets. The Government is however exploring floating PV modules on inland reservoirs.

In this White Paper we therefore **assume a conservative penetration rate of only 33%, or 2GWp**.

Two Gigawatts peak of installed PV will generate **2.4TWh per year, or 4.8% of 2025 forecasted electricity demand by 2025**, which is too substantial a figure to ignore when projecting Singapore's energy mix.

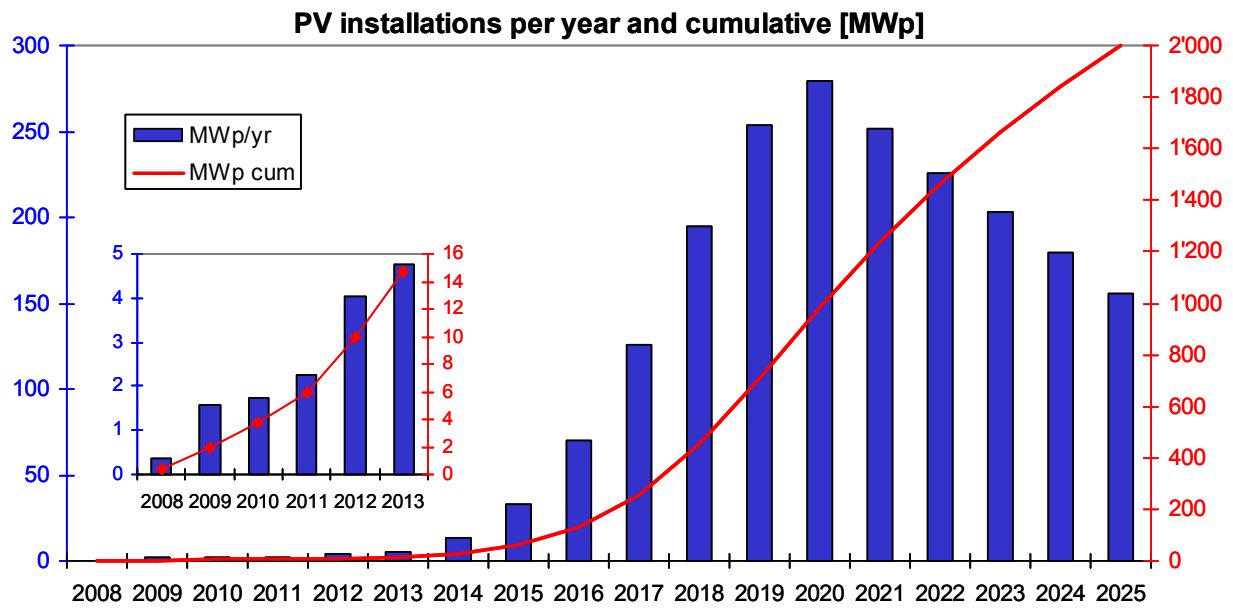
According to EMA, there were 14'746kWp of PV systems connected to the grid in Singapore by the end of 2013. The non-household sector constituted about 91.9% (or 13'548kWp) of total capacity, with the remaining capacity contributed by household installations. This meets less than 1% of Singapore's electricity demand.

Thanks to the attractive commercial and environmental returns of solar PV, there is a growing demand for bigger PV systems and the PV installed capacity looks set to more than double in 2014, exceeding 28MWp.

[4] GWp = Gigawatts peak. The nominal or rated generating capacity of PV modules and solar power plants is measured in Wp.

[5] Source: SERIS (NCCS-NRF Solar Energy Technology Primer Workshop, 14 Apr 2011): Net usable area on buildings, LRT tracks, islets and reservoirs = approx 60-65km².

If this growth rate continues, the 2GWp target will be achieved already by 2020. But again for this white paper we are assuming a conservative compound annual growth rate (CAGR) of only 1.5, to reach the projected 2GWp of installations by 2025.



Data source: EMA (2008-2013 figures)

Fig 5 Recent and forecast growth in PV installations

It is important to understand how the right regulatory and commercial conditions can drive rapid growth in PV installations. Germany is the best example to demonstrate this point, after having enacted laws to promote renewable energy via feed-in tariffs[6] (FiT) and providing priority access to the grid.

Because of lower sunshine levels and much higher PV costs at the time, Germany used feed in tariffs to create the right commercial conditions for PV growth, and these are essentially a market-distorting subsidy. Singapore enjoys higher sunshine levels than Germany does, and meanwhile the cost of PV panels fell dramatically during 2010-2012. Since 2013, these factors result in attractive commercial returns for PV installations in Singapore, with no need for any subsidies. What is needed now is the right regulatory environment for Singapore to capitalise on the competitive market situation by installing more PV systems. Creating a level playing field will ensure that PV and other RE technologies will play a significant role in Singapore's energy portfolio.

Let's compare growth rates for Singapore not with the whole of Germany, but only the state of Bavaria, whose population of approximately 12m is just over twice that of Singapore. Thanks to Germany's FiT, investors in Bavaria could earn attractive returns of 8-15% on solar power plants. In the four-year period from 2009-2012, Bavaria installed 5.4GWp[7] of mainly rooftop PV systems. This contrasts with our conservative target for Singapore of 2GWp in 12 years but this demonstrates that this projected target is achievable.

In conclusion, the target of **2GWp of PV installations in Singapore by the year 2025 is conservative and highly achievable**. There is scope for PV solar installations to comfortably exceed this figure.

[6] Germany's feed in tariffs guarantee a kWh tariff for all renewable electricity fed into the grid, for 20 years from the date of connection. The tariff varies according to RE technology, and is adjusted periodically for new installations, to reflect falling installation costs.

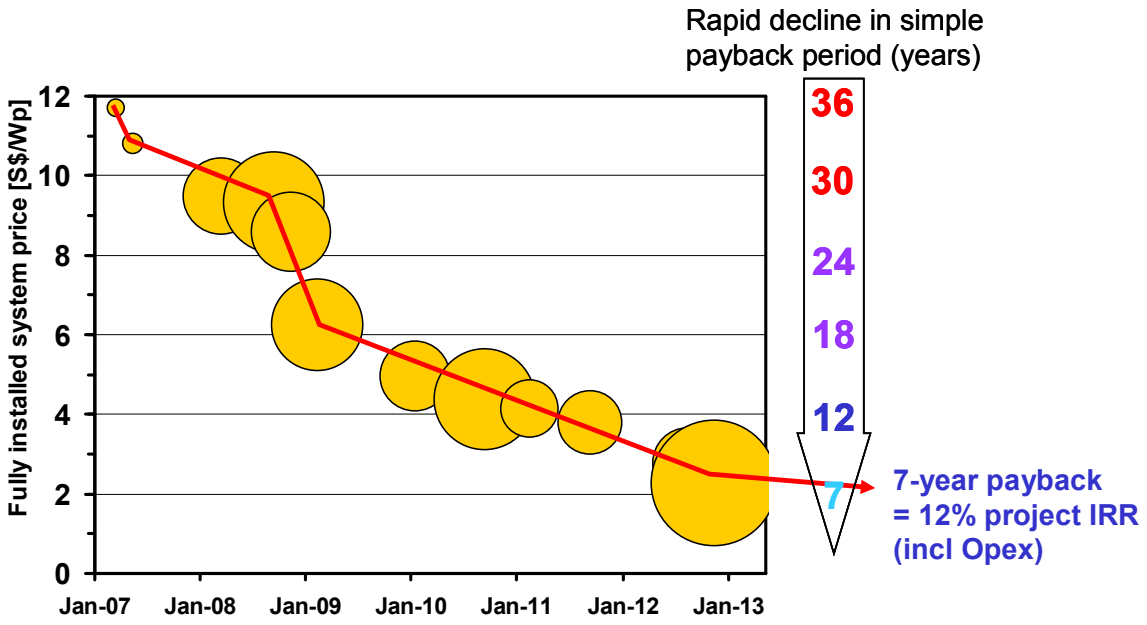
[7] Data from Germany's Bundesnetzagentur. From 2009-2012, Bavaria installed 5.356GWp of systems sized <500kWp (generally assumed to be rooftop systems), out of a total of 7.604GWp (roof and ground-mounted systems, all sizes)

3.2 The financial viability of PV

As a result of significant cost reduction in PV systems, relatively high electricity tariffs and attractive solar irradiation, PV power has become commercially viable in Singapore. With further growth in the global PV equipment industry and improving supply chain efficiencies in Singapore, installed system costs should continue to decline, albeit at a slower pace than in the past 2-3 years.

3.2.1 Solar PV payback periods are already attractive

Massive increases in global PV module production capacity have driven costs low enough in the last two years for a rooftop PV system in Singapore to pay for itself in 7-10 years, depending on system size. This results in an unlevered project IRR of 8-13%, making PV a very attractive investment, and one that needs no additional incentive schemes to justify its viability.



Source: Phoenix Solar commercial projects and GeBiz tenders. Prices at time of final offer (not at installation)
Bubble size in proportion to project size (kWp)
Payback period at 2013 retail tariff

Fig 6 Combined effects of system scale, cheaper PV panels and lower costs to install, resulting in PV system prices with payback periods of 7-10 years

To illustrate how to calculate the simple payback period of a PV system, let's consider the following:

- Specific yield of 1'250kWh of energy per year for each kWp of installed capacity. This varies according to site conditions and the quality of the PV system.
- Installed system price of SGD2.10/Wp (or SGD2'100/kWp) for a large rooftop system. This will vary according to system size and site conditions.
- Retail tariff of SGD0.24/kWh, being the avoided cost of buying power from the grid. This varies according to the customer's contract with the utility[8].

Then each SGD2'100 investment will generate 1'250 x 0.24 = SGD300 worth of electricity per year, resulting in a simple payback period of 2'100/300 = 7 years.

A more detailed payback calculation will need to consider the (relatively low) cost of annual maintenance

[8] In Q4/13, the retail tariff for non-contestable customers (residential and small commercial) is SGD0.2608/kWh. The peak (daytime) tariff for contestable consumers buying from SP Services under the High Tension (small) category is SGD0.2417/kWh.

(opex), the gradual decline in the annual output of the system, and the forecast electricity retail tariffs from the grid.

Many building owners are comfortable with simple payback method to determine whether an investment is worthwhile. Each will have his or her own benchmark, but payback periods of 6-8 years on an asset that lasts for 25-30 years are generally considered attractive.

Note that simple payback periods do not consider the opportunity cost of funds (equity hurdle rates and interest rates) used to finance the PV system.

3.2.2 Levelised Cost of Electricity (LCOE)

The cost of a PV system can also be calculated using the Levelised Cost of Electricity (LCOE) methodology, which calculates a cost per kWh that is representative of the whole lifecycle cost of the system and considers the opportunity cost of the investment.

LCOE is a more complex calculation than the simple payback period, with many more variables, but it is more typically used to determine prices in long term power purchase agreements (PPA). Note that the conventional LCOE calculation does not consider the utility retail tariff; instead, the LCOE is used in *comparison* with the utility tariff.

LCOE definition:

The present value of the total cost of building, operating and decommissioning a PV plant over its economic life, converted to equal annual payments and divided by yearly electricity production.

LCOE formula:

$$\text{LCOE} = \frac{\text{CAPEX + PV (O\&M)}}{\text{PV (EP)}}$$

CAPEX: Capital Expenditure
O&M: Operation & Maintenance cost
EP: Electricity Production
PV: Present Value

Based on current system cost in Singapore, the LCOE for solar electricity is around **SGD0.15/kWh,** already below the retail tariff of electricity in Singapore. Using the same costs (SGD2.10/Wp) and specific yield (1'250kWh/kWp/yr) as for the simple payback example above, Table 3 below shows an LCOE of 14.96 to 15.88 cents/kWh, according to a cost of equity ranging from 7% to 9%.

In SGD		System cost [SGD/Wp]							
		1.80	1.90	2.00	2.10	2.20	2.30	2.40	2.50
Cost of Equity	7%	0.1331	0.1386	0.1441	0.1496	0.1551	0.1606	0.1660	0.1715
	8%	0.1370	0.1427	0.1485	0.1542	0.1600	0.1657	0.1715	0.1772
	9%	0.1408	0.1468	0.1528	0.1588	0.1648	0.1708	0.1768	0.1828

Notes: Levelised Cost Of Energy (LCOE) calculations assume:

1. Annual O&M and lease cost of SGD 40k per MW with 3% annual inflation in cost
2. Electricity generation of 1'250 kWh/kWp in first year
3. Output declines linearly by 10kWh/kWp/yr (0.8% of initial output)
4. System life of 25 years
5. 75% of the project cost is debt funded at 5% interest rate
6. Accelerated depreciation in 1 year

Table 3: LCOE of PV electricity. Sensitivity to installed system cost in SGD/Wp, and investor's hurdle rate (cost of equity)

3.2.3 Economic benefits of solar PV

Assuming average system prices that will gradually decline from a range of SGD2.00-3.00/Wp today, to perhaps SGD1.25-1.80/Wp by 2025, two Gigawatts of PV will require **SGD3-4 billion in total investment.** This investment will come from the private sector, and not from the government.

The share of these investment flows that remain in the country will depend on the share generated from Singapore-based players, which also depends on policy and incentives in place. Assuming half of components / labour is sourced locally and not imported (Singapore hosts one international module manufacturer (REC), and several installation firms, investors and consultants) the in-country investment flow is ~SGD2 billion.

As one of the main Asian financial hubs, Singapore can be the home to a growing number of clean tech investments funds, and more RE companies may be encouraged to list on the SGX.

3.2.4 Creating jobs

An increased uptake of PV will create clean tech/renewable clusters in Singapore that will help to build a sustainable green economy and create more "green" jobs. 30% to 70% of value can be added locally, depending on where the PV modules are made[9].

The PV industry is creating jobs all along the value chain from the production phases to the installation work. The European Photovoltaic Industry Association (EPIA) estimates that PV module manufacturing creates 3 - 7 direct[10] jobs in production zones and about 12-20 related indirect[11] jobs for each MWp of solar power modules produced and installed on a world-wide average (whole PV value-chain, incl. research centres, installers, producers of silicon, wafers, cells, modules and other components). This will remain highly relevant for export regionally and globally, building capacities (in terms of skills and expertise) for local companies who can then expand into regional and global markets.

As *annual* PV deployment in Singapore grows from 10MWp in 2013 to 200MWp by 2017, employment could increase by a similar factor. Using EPIA's figures, with 30 FTE for solar EPC and O&M by end of 2012, this could increase to 6'000 FTE from 2017 onwards.

[9] Modified from IRENA 2011 RE jobs, to allocate 10% to independent admin/professionals, 20% to engineering, construction and supervision, and 40% if modules are sourced from local manufacturing.

[10] Direct jobs: jobs provided by companies or individuals fully dedicated to the PV chain in a range of positions and levels.

[11] Indirect jobs: jobs supporting the PV industry by providing generic components and services or administrative or tax services.

4. THE BUSINESS CASE FOR BIORENEWABLE ENERGY - BIOMASS AND BIOGAS

In this section we set our analysis of cost competitiveness or economic viability of biomass and biogas in the Singapore context.

4.1 Current general solid waste management system (incineration plant)

The collection and disposal of waste is a well-developed industry in Singapore. It is underpinned by the least cost of abatement, which is the incineration of waste, with electricity being sent to the grid and ash being sent to Pulau Semakau (an offshore land fill).

This model has remained unchanged for a number of years with the tipping fee at the incinerator gates being the commercial indicator that decides the marginal cost for recycling and energy recovery. NEA is implementing mandatory waste generation reporting for larger producers of waste. Waste Collectors are assigned areas to collect and make money where possible from simple recycling of PET and other higher value items in MRF (Material Recovery Facilities).

Due the high land cost in Singapore, no separation of organics to make biogas currently takes place at MRFs. Moreover, there is no segregation at generation sites of organics, as this is not required by law. HDB have undertaken some research in segregation organics from household waste in HDB estates. This is the limit to the value addition to waste generated in Singapore at the moment. Table 4 below shows the current status of general waste to energy plant in Singapore:

S/N	Type of Waste	Organisation	Location	Status	Notes
1	General Solid Waste	National Environment Agency incinerator plant (IP)	Tuas IP	In operation (until 2018)	1'700 tonnes per day capacity. Avg 9.2MJ/kg (2008-2012) 30 MWe of power. Ash sent to Pulau Semakau.
2	General Solid Waste	National Environment Agency incinerator plant (IP)	Tuas South IP	In operation (until 2030)	3'000 tonnes/day capacity, generating 80MWe Avg 9.84MJ/kg (2008-2012)
3	General Solid Waste	Keppel	Senoko Waste To Energy (WTE)	In operation (until 2024)	2'100 tonnes of solid waste per day capacity. 56 MWe
4	General Solid Waste	Keppel	Keppel Seghers Tuas WTE plants	In operation (until 2034)	800 tonnes of solid waste per day to generate about 22 MWe
5	Industrial & Commercial Waste	Sembcorp Industries	Jurong Island	Under development (due in 2016)	140 tonnes/hr of high pressure steam, from 1'000 tonnes day of waste

* MWe = MW of electrical power, while MWth = MW of thermal power

Table 4 Singapore's current general waste-to-energy plants

4.2 Waste statistics and recycling rate for 2012

The National Environment Agency publishes Singapore's waste production and recycling waste. In 2012, the overall recycling rate was just shy of 60%.

Opportunities to capture all biomass (wood waste and horticultural waste) and converting food waste to biogas are covered in this section.

Waste type	Waste disposed of (tonnes)	Total waste recycled (tonnes)	Total waste output (tonnes)	Recycling rate (%)
Construction debris	9'100	1'282'700	1'291'800	99
Used slag	9'800	358'000	367'800	97
Ferrous metals	54'800	1'331'200	1'386'000	96
Scrap tyres	2'300	16'100	18'400	88
Non-ferrous metals	25'200	97'300	122'500	79
Wood/timber*	**107'800**	**236'000**	**343'800**	**69**
Horticultural waste*	**139'800**	**108'000**	**247'800**	**44**
Paper/cardboard	555'300	696'700	1'252'000	56
Plastics	721'300	82'100	803'400	10
Sludge	160'200	0	160'200	0
Food waste	**618'100**	**85'100**	**703'200**	**12**
Textile/leather	141'000	18'300	159'300	11
Glass	55'400	19'500	74'900	26
Others (stones, ceramics & rubber)	333'800	4'600	338'400	1
Total	**2'933'900**	**4'335'600**	**7'269'500**	**60**

Table 5 Waste composition in Singapore (brown font = biomass feedstock, green = biogas feedstock)
* includes 110'300 tonnes used as fuel in biomass power plants
Source: http://app2.nea.gov.sg/energy-waste/waste-management/waste-statistics-and-overall-recycling

Other types of locally available waste that can be recovered to supplement biomass fuel in direct combustion are sludge waste (over 160'200 tonnes/year. Source: NEA) and solvent waste. They are generated mainly from waste water treatment, nutrition, biomedical and petrochemical industries. If disposed in an integrated incineration and high efficiency heat recovery system, such wastes can generate substantial electrical and heat energy.

4.3 Biomass and biogas power plant status in Singapore

Table 6 shows the biomass and biogas power plants in Singapore.

As reported in NEA Waste Statistics in 2012 in Table 5, biomass power plants have converted 110'300 Tonnes of biomass fuel to energy, contributing to the 56.5% recycling rate for combined wood/timber waste and horticultural waste.

Development status of biomass power plants:

- ecoWise currently operates 2 biomass co-generation plants in Singapore, generating an estimated total electrical output of 2MWe and thermal energy of 13.5MWth.
- Sembcorp is currently constructing a biomass plant to supply only steam in Jurong Island.
- CGNPC Solar-Biofuel Power (S'pore) Pte Ltd has announced the development of a 9.9 MWe biomass power plant in Tuas.
- Kim Hock is operating 2 biomass power plants in Sungei Kadut and Jurong respectively.

Development status of biogas power plants:

- Public Utilities Board (PUB) is recovering an estimated 7MWe from 120'000 m³/day biogas. The biogas is used in the operation of plant process.
- A chicken waste to biogas to produce Combined Heat and Power (CHP) from 3 farms. It is estimated to recover 490 tonnes/day of chicken waste to generate approximate 50GWh of electricity per year and approximate 10MWth* of thermal energy output by 2020.
- IUT Global developed a food waste to energy (biogas) plant to produce 4.5 MWe & 5 MWth*. However, it closed due to feedstock supply problems.

S/N	Type of biorenewable energy	Organisation	Location	Status	Notes
1	Biomass	ecoWise Group	Sungei Kadut	In operation (Co-generation)	First CDM project in Singapore registered with UNFCCC
2	Biomass	Gardens By The Bay & ecoWise Group	Marina South	In operation (Tri-generation)	15-year DBO renewable energy supply to Garden's conservatory
3	Biomass	CGNPC Solar-Biofuel Power (S'pore)	Shipyard Crescent	Under development	First foreign owned biomass plant cum solar power in Singapore
4	Biomass	Sembcorp Industries	Jurong Island	Constructed	Supplying to Singapore petrochemical hub
5	Biomass	Kim Hock Pte Ltd	Sungei Kadut & Jurong	Constructed	-
6	Biogas	Public Utilities Board waste water anaerobic digestion biogas plants	Changi WRP, Jurong WRP, Ulu Pandan WRP & Kranji WRP	In operation	Estimated 7 MWe* of power from 120'000m³/day biogas used in operation of plants. (source: PUB)
7	Biogas	Chicken waste to biogas combined heat & power CHP	3 farms	Under development	Estimate 490 tonnes/day by 2020, to generate ~50GWh/yr, plus approx 10MWth* output
8	Biogas	IUT Global Food waste to energy	Tuas	Closed down	4.5 MWe & 5 MWth* capacity closed due to feedstock supply issues.

Table 6 Biomass and Biogas Power plant Status in Singapore
*** MWth = MW of thermal power. MWe = MW of electrical power**

4.4 The Biorenewable energy opportunity in Singapore

Combining Biogas and Biomass, we will examine the collective case for "Biorenewable Energy".

Bio-energy fuel source	2025 feedstock [tonnes/yr]	Energy by 2025 [GWh/yr]
Wood/timber & horticultural waste	***770'400***	***785***
Food waste	834'000	300
Chicken manure	150'000	50
Subtotal - Biogas		***350***
Total – Bio-energy		***1'135***

Table 7: Bio-energy forecast to generate 980GWh/year by 2025.

4.4.1 Biomass power plant technologies – electricity only, co-generation and tri-generation

There are 3 main types of biomass power generation systems and the types and total system energy efficiencies are shown in **Fig 7** below.

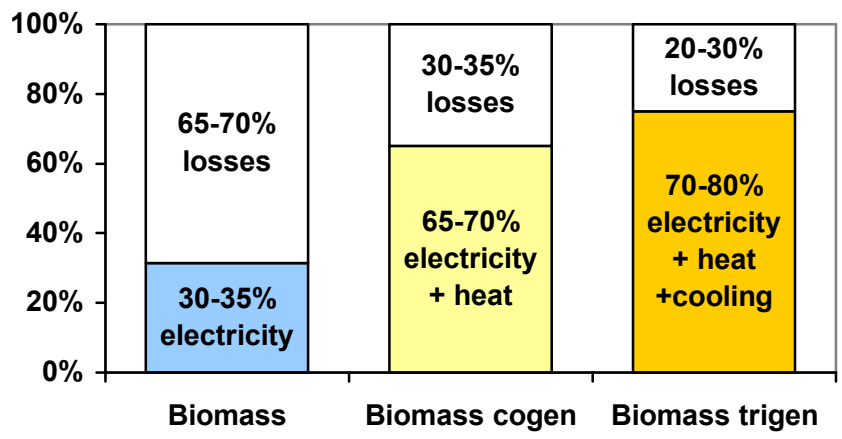


Fig 7 Comparing efficiencies for biomass power plants

Generating electricity only

Conventional fully condensing biomass power plant generates only electricity, and with quite a low efficiency. Approx 30-35% of the input energy is converted to useful electricity, while the balance 65-70% is lost as heat.

Co-generation

Under the REPORT OF THE INTER-MINISTERIAL COMMITTEE ON SUSTAINABLE DEVELOPMENT prepared by Ministry of the Environment and Water Resources and Ministry of National Development, one of the key recommendations in Chapter 7 – Work-Resources – Efficient Industries For Sustainable Growth is to promote more energy-efficient technologies and systems, such as co-generation and tri-generation with power generation plants and industrial facilities, and green data centres.

Biomass co-generation plants extract useful heat for industrial applications during generation of electricity. Harnessing the recovered heat increases system efficiency compared to fully condensing power plants. The heat can be used for drying purposes, process heating, etc. A biomass co-generation plant installed at Sungei Kadut illustrates this principle. It taps the heat to dry spent grain (approx. 65% moisture content) from an F&B manufacturing plant and repurposes it as animal feed.

Tri-generation

With a tri-generation plant, additional heat energy is put through an absorption chiller system to produce chilled water for cooling purposes. A feasible tri-generation plant should be located within a plant/cluster of plants that require combined cooling, heating and electrical power, resulting in the highest system efficiency (75-80%).

The biomass power generation technology using a co-generation or tri-generation system is already commercially available. The biomass plant at the Renewable Energy Centre of Singapore's iconic Gardens By the Bay is a tri-generation power plant which is designed, built and operated by ecoWise (a home grown environmental company) since January 2012. **Fig 8** shows the process schematic for this plant.

In Singapore, a company is required to hold a Wholesaler (Generation) Licence issued by the Energy Market Authority (EMA) if its electricity generating equipment exceeds 1MW of nameplate capacity and is connected to the grid.

In this case, to avoid exceeding the 1MWac threshold for unlicensed generation, the plant's design was limited to 929kW of electricity and was biased towards heat and chilled water supply.

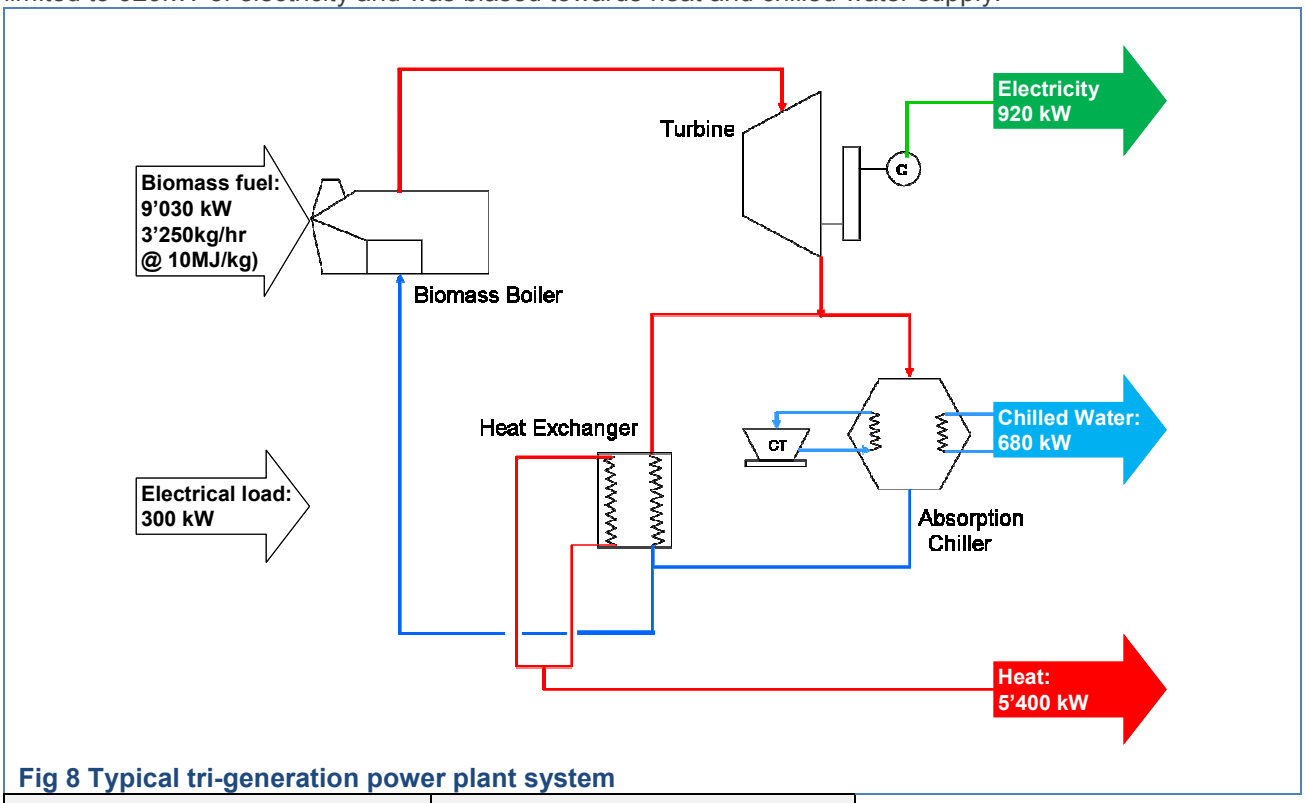


Fig 8 Typical tri-generation power plant system

Input		Output	
Biomass	9'030 kW	Electricity	920 kW
Electricity	300 kW	Thermal power	5'400 kW
		Chilled water	680 kW
Total	**9'330 kW**	**Total**	**7'000 kW**
Overall efficiency = output/input = 75%			

Since biomass waste inherently provides a good source of energy, the relevant authorities in Singapore should therefore only support or grant licences for future biomass projects that adopt at least a co-generation power scheme, to maximise the recovery of useful energy from such waste.

The general guideline for the capital investment of a biomass co-generation system is about USD2'000-2'500/kW of installed output *(IEA Bioenergy website: www.aboutbioenergy.info/economy_investment.html).*

The capital investment in Singapore tends to be higher due to higher construction and project implementation costs.

The return on investment of such plants depends largely on the following:

1. Cost of biomass fuel (fuel cost forms approximately 70% of total operating cost)
2. Plant efficiency (typical co-generation plant efficiency ranges from 50-70% depending on equipment selection including biomass boiler, steam turbine generator etc)
3. Operating hours in a year (typically 7'000 - 8'000 operating hours in a year)
4. Capital investment cost.
5. Plant capacity for electrical output and steam output.

S/N	Company	Capacity (MW) or (ton steam)	Investment (SGD)	Investment (SGD/kW)
1	CGNPC Solar-Biofuel Power (S'pore) Pte Ltd	9.9 MWe	42m	4'240 (estimated)
2	Sembcorp (Semb Industries)	No electrical generation 20 ton/h steam	34m	2'500 (estimated)

Table 8 Published information on investment cost for selected biomass plants in Singapore

4.4.2 Current biomass availability in Singapore

Singapore currently depends on horticultural waste and wood waste to produce biomass fuel. According to 2012 statistics published by NEA, out of 591'960 tonnes/year (average of 1'622 tons/day) of biomass waste derived from horticultural and wood wastes, only 344'000 tonnes/year (average of 942 tonnes/day) are recycled as reused wood and biomass fuel. This represents a recycling rate of 58.1%.

Already in 2012, NEA statistics show that 110'300 tonnes of wood/timer and horticultural waste were used to fuel biomass power plants.

Waste type	Total waste output (tonnes)	Total waste recycled (tonnes)	Waste disposed (tonnes)	Recycling rate (%)
Wood/timber	343'800	236'000	107'800	69
Horticultural waste	247'800	108'000	139'800	44
Total	**591'600**	**344'000**	**247'600**	**58.1**

Table 9: Biomass waste output, recycled and disposed in 2012.
Source: http://app2.nea.gov.sg/energy-waste/waste-management/waste-statistics-and-overall-recycling

4.4.3 Potential biomass energy from horticultural and wood waste

With an enormous area under greenery (the government's "city in a garden" concept), Singapore produces a large amount of wood and horticultural waste (clippings). This sector is seeing significant investment and is expected to be fully exploited within the next few years.

The average annual increase for biomass waste from 2008 to 2012 was 4.5% per year. Much of the wood waste is driven by the construction sector, which looks set to continue for a few years before levelling off. Horticultural waste comprises mostly garden waste and tree pruning, and is less likely to grow. Assuming that the past rate of growth for total biomass waste is maintained for the next five years, then the total biomass waste from 2013 to 2018 shall increase at the same 4.5% rate and then stabilise from 2018 onwards at 770'400 tonnes/year (2'100 T/day).

In August 2012, NEA imposed restrictions to prohibit disposal of recyclable wood waste to the four public incinerators. As a result, we anticipate that that more and more such waste will be recycled as biomass fuel.

Fig 9 shows the amount of biomass waste that will be recycled; assuming that the current recycling ratio of 58% will increase by 10.5% per annum to reach full recovery by 2016.

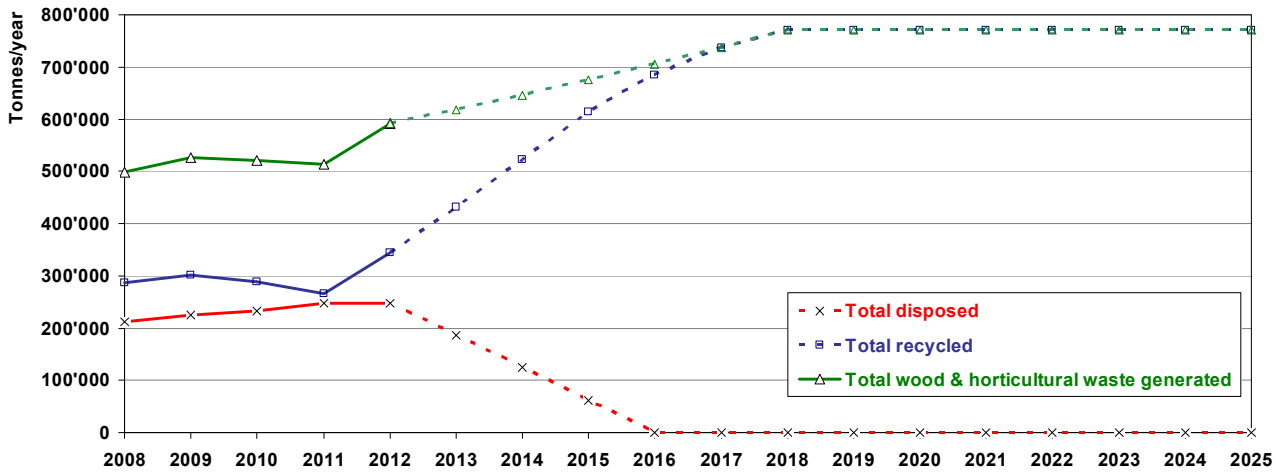


Fig 9 Historical & projected growth of biomass waste (wood & horticultural) availability in Singapore (2008-2018). Ref: Data from NEA Waste Statistics (2008-2012)

Notes:-

1. **Horticultural and wood wastes quantity (2013-2025) estimated based on historical data from 2008 to 2012.**
2. **Availability of horticultural and wood waste is estimated to remain stable from 2018 onwards and achieve NEA target of recycling 100% of these wastes.**

Fig 10 below shows the potential growth of biomass energy, under the following assumptions:

- Biomass feedstock = wood/timber and horticultural waste, which continues to grow at 4.5% annually until 2018, when it levels off.
- Recycling rates increase from 58% in 2012 to 100% by 2016.
- Average energy content of biomass in 2'300kCal/kg, or 2.67MWh/tonne.
- Conversion efficiency for simple biomass power plants is 31%, and for CHP plants is 68%.
- Recovery of available wood/horticultural waste to make biomass power with conventional power systems grows linearly from 32% in 2013 to 80% in 2025.
- CHP share of total biomass plants starts at 45% in 2012, dropping to 35% when CGNPC 9.9 MWe power plant (non-CHP) starts operation in 2014 and returning to 45% from 2016 as new CHP plants are constructed. This is a conservative assumption.

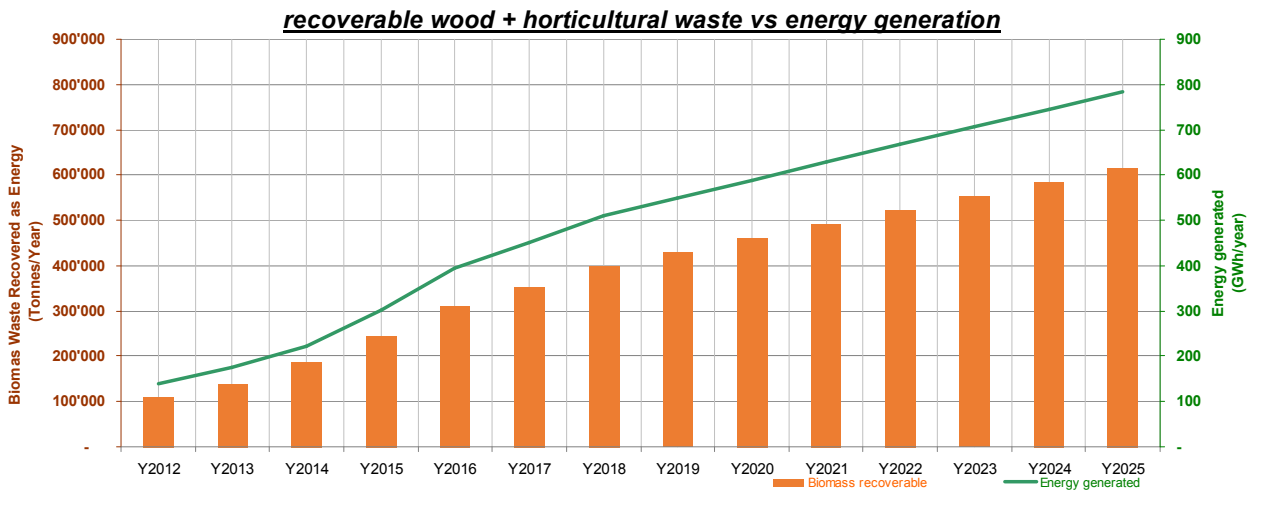


Fig 10 Growth forecast for energy generated from recoverable wood + horticultural waste

The above growth scenario leads to 785GWh/year from biomass power plants by 2025. This is conservative and the figure can be much higher, if Singapore promotes CHP and tri-gen plants co-located with off-takers that can exploit the heat and chilled water production from such plants for their operations (such as biomedical park and water parks).

4.4.4 Other possible technologies to extract energy from biomass fuel

In addition to the direct combustion method of recovering energy from biomass waste, there are other types of thermo-chemical conversion method that are either in operation or R&D phases, as shown below.

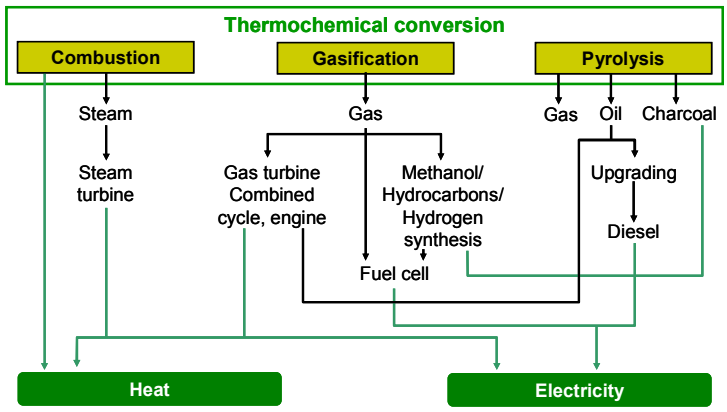


Fig 11 Thermo-chemical conversion routes to produce heat and electricity

4.5 Biogas generation from organic waste

4.5.1 Food waste

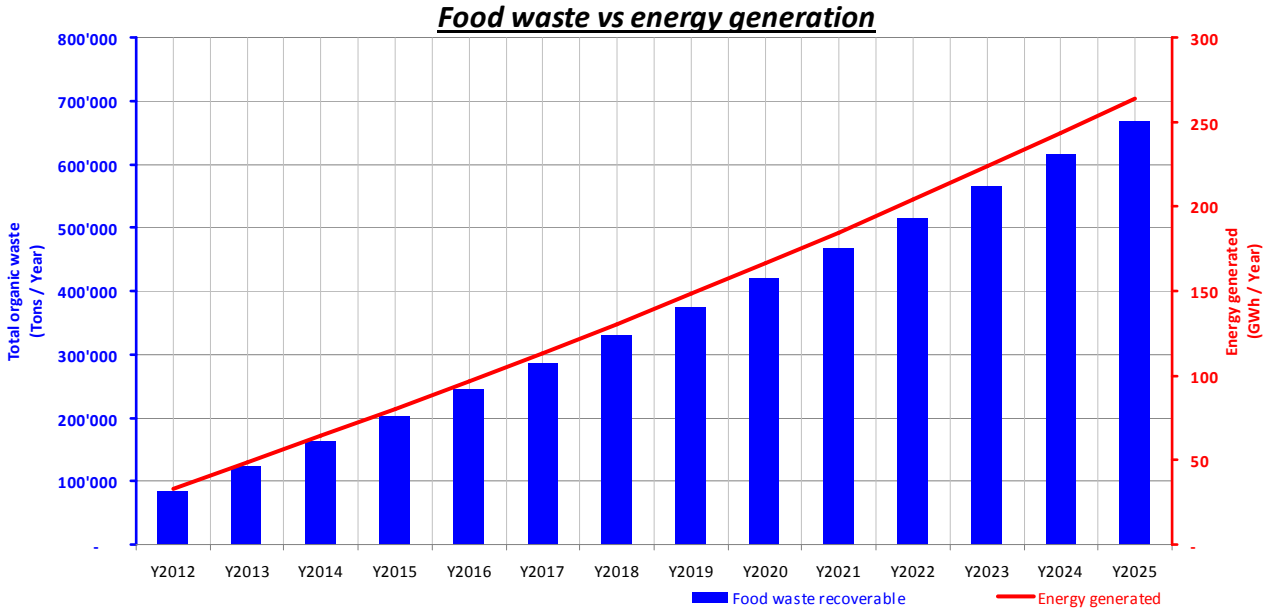


Fig 12 Growth forecast for energy generated from food waste: 264GWh in 2025

Fig 12 shows the potential to generate 264GWh per year of energy from food waste by 2025. This is based on a number of assumptions:

- Organic food waste will grow in direct proportion to Singapore's population, which will reach 6.3m by 2025 (see **Fig 4**). Thus food waste will is forecast to grow from 703'200 tonnes in 2012 to 834'000 tonnes in 2025.
- Recovery of food waste improves from 12% in 2012 to 80% by 2025.
- Anaerobic digesters produce 150Nm³ of gas per tonne of recoverable food waste, with 60% CH_4 (methane) content. (Nm³ is a cubic metre of gas under normal atmospheric pressure.)

- CH_4 has a density of 0.66kg/m³ and an energy value of 55.7MJ/kg.
- Gas engines operate with an efficiency of 43%.

Thus each tonne of recoverable food waste generates 150 x 60% x 0.66 x 55.7 x 43% = 1'423MJ = 395kWh.

It makes sense to divert food waste from incineration to feed anaerobic digesters because food waste has a high moisture content, which reduces the net calorific value (NCV) of incinerated waste. If incinerators need to burn wet fuel, they lose significant energy to vaporise the water content.

The above case assumes all biogas plants operate as stand-alone, without harnessing the waste heat. However, Combined Heat and Power (CHP) or tri-gen plants will increase total operating efficiency to approx 68% and 75% respectively. Where possible, biogas plants should be co-located with an operation that takes advantage of the heat by-product.

Conservatively, we assume a mix by 2025 of:

- 80% are stand-alone systems @ 43% efficiency
- 10% combined heat and power (CHP) @ 68% efficiency
- 10% tri-gen @ 75% efficiency

This results in a potential energy production of 300GWh from food waste by 2025.

4.5.2 Chicken manure

Singapore currently has 3 chicken farms, all of which are scheduled to expand operations significantly as part of Singapore's efforts to decrease its dependence on imports.

By 2025, each chicken farm will have 1.3 to 1.5 million chickens, which each produce approx 100g of manure daily. This comes to approx 50'000 tonnes per year for each farm.

Fig 13 below illustrates the conversion of manure feedstock to 60% methane gas in an anaerobic digester (AD). The gas then powers a gas engine to generate electricity. Some of the waste heat is recovered to maintain the AD at an optimum operating temperature of approx 43-44°C for the microbes to do their work.

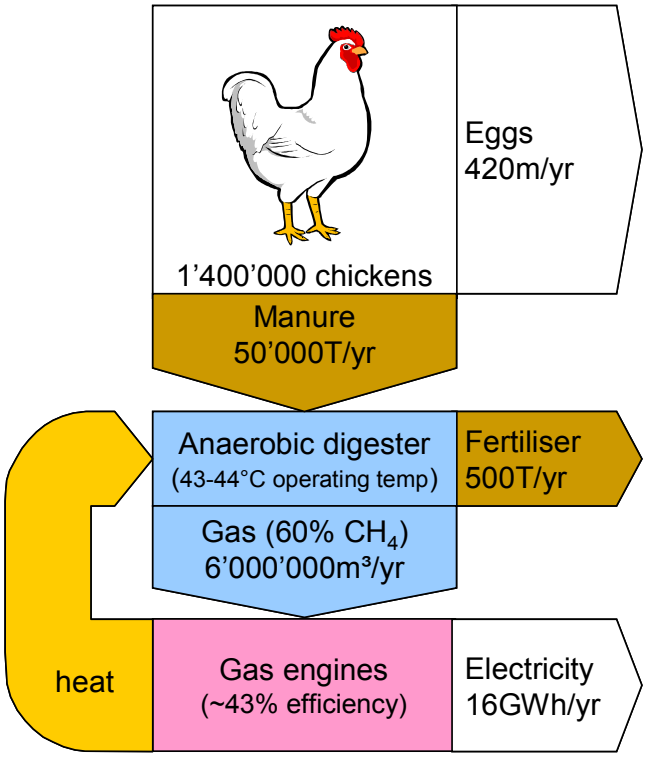


Fig 13 Operating principles of biogas power plant using chicken manure as feedstock

Between them, the three chicken farms can produce close to 50GWh a year of electricity by 2025 from captive biogas power plants.

4.6 Financial viability

4.6.1 Financial returns for each category (typical order of magnitude)

As we can see from the energy recovery or efficiency level for each type of generation, higher recovery leads to higher returns on investment. Depending on many factors such as biomass fuel cost, selling prices of electricity and steam, total cost of capital expenditure, etc. the estimated internal rates of return for each category of generation are as follows:

	Electricity only	Co-generation system	Tri-generation system
Estimated IRR	16%	19%	22%

Hence it is obvious that the investor risk will be reduced if the biomass power is built to produce at least two types of power, supplying to customers that require both electricity and steam. These figures assume a fixed supply of biomass with no supply risk. Where biomass feedstock is risky, return premiums required by investors go up and the hurdle rate needs to increase.

Biomass and biogas are already financially viable, and they will be even more so by 2025, due to expected changes in the market conditions. We expect changes in the way value is added to waste from its generation to ultimate disposal. Let's explore the commercial sensitivities of these projects and the benefits to the economy and community.

Biomass power from horticultural waste is generally quite homogeneous (or consistent). There is a large amount of it available and there are already projects underway exploiting commercially available technologies. This is the low hanging fruit of renewable energy in Singapore and is expected to be fully exploited within a few years.

Project economics for a merchant plant where fuel supply costs and availability are sourced from the market are outlined below:

In SGD		Fuel cost [SGD/Tonne]							
		15	25	35	45	55	65	75	85
Cost of Debt	9%	0.1375	0.1625	0.1888	0.2040	0.2250	0.2380	0.2580	0.2750
	11%	0.1438	0.1657	0.1882	0.2050	0.2245	0.2395	0.2583	0.2753
	13%	0.1500	0.1688	0.1875	0.2060	0.2240	0.2410	0.2585	0.2756

Assumptions for biomass

1. Capital cost per megawatt based on consumer industrial market price of SGD 3.5m/MWe
2. Plant life is 12-15 years, assuming boiler refit after 10 years
3. Energy yield is approx 400kWh/tonne of feedstock (35% moisture content)
4. Project funded on non recourse finance (60% debt)
5. Equity funding at 21% (hybrid rate)
6. Ash to be sold at SGD 25/Tonne
7. Carbon credits are ignored, as are heat sales
8. Mandated NEA rules will result in 90% collection and processing.
9. The current delivered cost of biomass of under SGD 35/Tonne.

The LCOE for biomass is approx SGD0.19/kWh, based on current feedstock pricing of SGD35/t delivered to the plant.

Biogas projects are highly sensitive to the cost of feedstock.

The current least cost of abatement at the incinerator plants (IPs) is SGD 77-87/Tonne. This is based on a mix of all types of waste. Biogas needs the putrescible portion, which has high moisture content and generally doesn't generate a lot of energy in the IPs.

Biogas plants need to remove the non digestible waste from the putrescible waste. This non digestible waste needs to be sent to the IPs or other recyclers. As such, the quality of sorted waste and amount being sent for reprocessing is important. Conversely, this makes sorted waste streams more attractive with a higher value.

In the table below, a negative feedstock cost represents a "tipping fee", where waste collectors must pay to deposit their waste. But this scenario is unlikely if waste is sorted before delivery. Biogas projects will not be

paid a tipping fee from the waste collectors delivering the waste, but will actually have to pay for the value addition from sorting.

In SGD		Feedstock cost [SGD/Tonne]							
		-10	-5	0	5	10	15	20	25
Cost of Debt	9%	0.0700	0.1000	0.1300	0.1620	0.1920	0.2215	0.2510	0.2800
	11%	0.0725	0.1015	0.1310	0.1630	0.1925	0.2218	0.2515	0.2810
	13%	0.0750	0.1030	0.1320	0.1640	0.1930	0.2220	0.2520	0.2820

Assumptions for biogas:

1. Capital cost per megawatt based on consumer industrial market price of SGD 3m/MWe
2. Plant life is 12-15 years, assuming engine replaced after 7 years and boiler refit after 10 years
3. Project funded on non recourse finance (60% debt), with interest rates in the 9-13% range
4. Average cost of equity is 21% assuming no Government mandated supply agreements for feedstock
5. Recyclables are sold at SGD 70/Tonne
6. Bio-fertiliser by-product is sold at SGD 50/Tonne
7. Carbon credits are ignored, as are heat sales
8. Mandated food waste and digestible organics to be collected with 90% collection and processing
9. A feedstock cost of SGD 10/Tonne is the most likely scenario given the high transport and land costs in Singapore (assuming no law mandating source segregation of food waste from other recyclables).

This results in an LCOE of approximately SGD0.19/kWh for a stand-alone biogas plant using the organic faction of Municipal Solid Waste (MSW). The LCOE improves for captive plants that can harness the co-gen heat energy or tri-gen heat and chilled water output.

The financing costs for biomass and biogas are much higher than for solar PV, mainly due to the higher risk of feedstock supply as discussed earlier. Equity is actually divided into two layers. Lead investors accept a lower return of around 15% in exchange for taking priority over developers and promoters, who expect returns of 25% to reward their higher risk. They come last in line after debt and equity with charges over assets. A hybrid rate of 21% has been used to compute LCOE.

Chicken waste biogas has a higher IRR with a lower capital cost. As the waste is generated at site, the feedstock cost is nil. In addition, the farmers would need to remove ammonia prior to sale as fertiliser. The farmer gets a heat dividend from the power from the biogas engines We see an increase in technology investment capital resulting in revenue of SGD 3 million by 2020 using chicken waste, and SGD 13 million using organic waste. This is the low hanging fruit for biogas in Singapore.

The levelised cost of energy for chicken waste to biogas, when coupled with heat recovery for feed drying, is below SGD 0.07/kWh. The improved economics come from the captive nature of the plant, the combined heat and power dividend, and the reduction in operating expenses for bagging.

A potential solution to reduce the levelised cost of Biogas derived energy is to co-locate biogas plants at waste collectors Material Recovery Facilities (MRFs). There will be a cost to ship the non-digestibles and sludge to the incinerator plants but this will be reduced by the overall load size reduction. The issue is finding land adjacent to MRFs. Insufficient data are available to accurately predict the LCOE for this configuration.

The table below summarises the expected LCOE based on prevailing industry business models and risks.

LCOE (SGD/kWh)	Captive/distributed	Intermediate/MRF	Stand alone plant
Biomass	0.13	0.16	0.19
Biogas	0.07	0.13	0.19
Biogas from MSW	0.07	0.16	0.19

The sensitivity to feedstock costs is directly related to the least cost of abatement (disposal ie incinerator plants) and ability to site near the waste generation location (distributed location).

4.7 Economic benefits

As shown in the sections above, there is a lot of potential for "green" investors or fund managers in biomass co-generation plants in Singapore. The critical factors that determine the optimum size or scale for such plants are:

- Location of plant where there are clusters of end-users that require steady supply of electricity and steam (or chilled water) and are willing to commit to long term supply and purchase contracts, such as the MNCs in biomedical and wafer parks.
- Proximity to supply of biomass fuel and other wastes that can supplement the biomass fuel.
- Investors' ability to secure essential support from the relevant authorities to make such multi-faceted investments financially more attractive with manageable risks.

With experienced process design, engineering and operation and maintenance personnel to implement such projects, the cost of producing electricity and steam can be competitive enough to enable contractual end-users to enjoy cost savings, as compared to the current supply sources. The economics for all parties will improve drastically should the prices of fuel oil or gas landed at Singapore increase.

4.8 Other tangible benefits for Singapore

In addition to the potential return on investment for high efficiency biomass co-generation and tri-generation power plants, such projects also create many other non-financial benefits to both the industry and the country as a whole:

- Since a biomass co-generation plant is like a mini-power plant involving almost all disciplines of engineering and with high degree of automation, investments into these projects will create rewarding employment for PMETs. Singapore can build up a talent pool in the bio-energy sector.
- Reduce the amount of waste going to public incinerators and hence less ash will be sent to the limited landfill space at Pulau Semakau, as all the secondary waste produced from a well-designed biomass co-generation power plant can be repurposed for other uses.
- The concept of building district biomass co-generation or tri-generation plants within a biomedical or wafer park will bring better sharing / integration and utilisation of costly facilities and limited land space. This integrated approach is currently being mooted jointly by EDB, JTC and a local environmental company with good track record in development of notable biomass power plants. Such district power plants will enable local environmental companies to work closely with MNCs to achieve sustainable development and showcase Singapore's unique capabilities in this field.
- With high recovery ratio of energy from the biomass fuel, the industrial clusters that buy the green / renewable energies (electricity / heat / chilled water) are likely to enjoy cost savings for these utilities compared to the current sources of supply (either electricity from power companies or heat from gas boilers). This will enable EDB and JTC to attract investments into the key biomass medical or semiconductor/wafer parks.
- Promotion of Corporate Social Responsibility (CSR) of companies, lead by MNCs operating in such Biomedical and Wafer parks.
- Tapping the support of government agencies such as IE Singapore, this business model can be exported to other countries (such as China, ASEAN and India) where there is abundant biomass waste and a great need for electricity, thermal heat and air-conditioning.

5. MOVING FORWARD

This section addresses the remaining key framework conditions to increase RE penetration, distributed generation, system integration, and market mechanisms for the sale of renewable electricity and policy frameworks, including the hurdles preventing their implementation. Finally we also set out key recommendations to achieve the 2025 targets for RE in Singapore.

5.1 Towards distributed generation

The drive for energy efficiency and the reduction of greenhouse gas emissions means that Singapore must explore alternatives to the current centralised, fossil-fuel-based generation paradigm and decrease its dependence on traditional energy sources.

The best candidate to complement the existing electricity infrastructure is distributed generation, where electricity is produced close to its point of use. Co-location reduces costs of transmission and distribution.

Solar power plants on rooftops will supply the buildings beneath them, and any surplus power will supply the neighbouring buildings. This unburdens the centralised transmission and distribution infrastructure.

Combined Heat and Power (CHP) or tri-generation facilities have energy efficiencies in excess of 70%, or almost double that of conventional steam generation, by co-generating heating and/or cooling. Distributed generation e.g. CHP or tri-generation is therefore a highly desirable solution. The current market structure allows for the installation of power generators smaller than 10MW that are used solely for onsite demand i.e. they do not export power to the grid. The market also includes also embedded generation with much larger capacities, seen primarily in the petrochemical sector.

Distributed generation can reduce the cost of electricity to end users and even supply cooling to residential and commercial buildings in a more efficient manner. The key bottleneck is the accessibility to fuel. While solar is less of an issue, gas driven systems pose greater challenges.

In reviewing opportunities to locate other facilities underground, these energy systems can be constructed below the demand centres to supply energy (electricity, heating and cooling) more efficiently, while keeping noise away, and also freeing up land for other uses.

The proliferation of distributed generation systems raises concerns about the reliability of the grid, which was not conceived to accommodate a plethora of generation connected to the distribution network. Smart grid solutions for grid management, and business models like "interruptible load" and other Demand Response schemes (see Glossary), can mitigate these concerns. They open more possibilities to reduce the impact of distributed generators on grid reliability, by easing the strain on the grid during unplanned events.

5.2 Research and development: overcoming the challenge of intermittency

Intermittency is a genuine concern for grid reliability.

Singapore operates a wholesale electricity market. This market trades energy, reserves, and frequency response. Reserves are scheduled sufficiently so that if the biggest operating generator trips there will be sufficient spare spinning (fast response) capacity to fill the gap in supply and make sure consumers are not affected. Reserves can also provide for replacement of intermittent generation when that becomes unavailable. An example of this is when clouds suddenly obscure the sun’s rays from the solar panels. Presently reserve costs are reallocated to the big generators. This principle could continue with the introduction of solar power by applying some alternative reserve charge constructed specifically to deal with intermittent generation. The market provides adequate mechanisms to recover the cost of intermittent generation and provide for security of supply through interruptions.

Smart grid in the Singapore context is really about demand side management and smart metering. These were the main topics of the ongoing EMA IES project. Intermittency is a subject for renewables, predominantly solar and wind. With the small volumes expected in Singapore and spinning reserve levels of approx 500MW, intermittency does not yet pose a problem. Indeed EMA have recognised this and provisionally raised their hard cap for intermittent generators from 350MW to 600MW.

The policy is however needed to guide the market to: recover full cost of intermittency from solar generators; socialise the cost; subsidise through leaving all or part of the costs with the big generators as at present; or take some other approach. EMA has issued a Consultation Paper to address these issues.

6. CONCLUSIONS & RECOMMENDATIONS

Singapore is poised for regional leadership in solutions to adopt renewable energy if we take the lead in this and export our expertise. From the industry's point of view, we need a clearer alignment of legislation and economics; and we need to build knowledge and leadership.

A number of framework conditions need to be in place to achieve the 2025 RE targets: proving the cost competiveness of RE, paving the way for distributed generation; setting up a fair system integration approach to remove grid restrictions, manage intermittency and grid charges, setting up bilateral trade instruments for the sale of renewable electricity and developing the right policy landscape.

The following table captures all the recommendations included in this White Paper to deploy and support the penetration of RE in Singapore.

6.1 Recommendations

	Current Situation	Recommendation	Stake-holder
Market Regulation	Power wheeling Contracts for Differences already exist, but not possible for long periods, it is only a 2 – 3 year hedge. It is complex for the host and client.	Simplify electricity regulations to support power wheeling. Establishing market mechanisms for bilateral sales of energy, such as power wheeling, to match energy generated by a generator in one location to a buyer in other location will improve capital & operational efficiencies and ultimately business viability for larger scale distributed generation.	EMA
	Captive biomass power plants can only supply electric power to an off-taker within its premises	The economic feasibility of biomass power generation plants depends largely on plant scale and the ability to deliver both electrical power and heat (steam or hot water) simultaneously. Restrictions on provision and sale of electricity directly from a captive third party generator to cross-boundary customers should be relaxed. This will increase plant scale, improve capital and operational efficiencies and ultimately business viability. This applies to biogas plants as well. Since such plants contribute to the reduction of carbon emissions and National Carbon Footprint, government may consider granting more favourable terms for demand charges as backup from the electricity network to the biomass plant or end-users of electricity.	EMA
	Adjusting grid charges Grid charges do not reflect the true use of the grid infrastructure by RE sources feeding into the grid.	The renewable energy sector in Singapore is ready to pay appropriate grid charges, provided the charge is in accordance to grid segment used (i.e. High Voltage, Medium Voltage, Low Voltage). Taking PV as an example, the excess PV electricity fed into the grid typically only uses the local Low Voltage 400V network (see **Fig 15** in Annex 2). This segment costs <20% of the entire transmission and	EMA

		distribution network. If grid charges were imposed according to the grid segment used, they should currently drop by 80% (from 5.05 to 1 cent/kWp).	
	Allocated capacity and lower capacity factors for RE	Generation companies have a potential role in renewable energy generation in partnership with technology providers. Policy could look at the potential of each power generator to maintain an RE portfolio as a percentage of its energy generation allotment. Proposal — exclude RE from the Genco's cap. This is a bit like an RE tax for generators, and only practical if sufficient RE is available. Change CAP for each technology, from absolute capacity (undifferentiated) to: Nameplate capacity x capacity factor, eg: CCGT: 1 GW x 95% = 950 MW vs 1'000 MW PV: 100 MW x 14% = 14 MW vs 100 MW	EMA
Administrative	Redundant DC connection requirement for equipment (inverters, switches, etc) which was introduced in 2011 and which adds unnecessary cost and points of failure, without meaningfully increasing safety	Reconsider redundant DC connection requirement for equipment (inverters, switches, etc). The current requirement was introduced in 2011, although not clearly required by CP5. It adds unnecessary cost and points of failure, without meaningfully increasing safety. See Annex-1 for further elaboration	EMA
	The transmission licensee (SP PowerAssets Ltd)'s approval process for commissioning a renewable energy plant / system takes too long even though the plant type and systems may be similar to another prior approved project. Even replicated projects appear to require long approval timelines. We anticipate a rapid increase in the rate of PV installations, as greatly reduced PV costs make systems commercially attractive. However, commissioning approval will become a bottleneck unless it is streamlined.	Shorten and simplify approval process, particularly for replicated or similar projects. For example, pre-approve tried and tested inverter models, and delegate the commissioning test to the building LEW.	EMA/ SPRING
		Raise the licensing threshold from 1MW to a higher level. For PV, there are very few rooftops that are big enough to accommodate more than 5MWp anyway. So if the threshold could be raised to 10MWp, it is ample to avoid unnecessary requests for waivers.	EMA
		Licensing requirements for Distributed Generation (DG) should be lower than for Central Generation (CG) plants.	EMA
	Waste is not segregated in Singapore NEA has implemented a policy of restricting wood and horticulture waste disposal to the public incinerator, which is some form of separation. But, sufficient amounts of pure homogeneous food waste are still difficult to obtain.	Segregating Our Waste One way to fully harness the power potential of biomass and biogas is to legislate waste as a "Designated Commodity" where companies are required to add value and report the waste they generate. By segregating our waste and treating it in a designated way, we have more opportunity for new and emerging clean tech industries. The more	NEA

		homogeneous or easy to treat a waste, the higher its value. More heterogeneous waste will cost more to treat. This will incentivise efficiency by requiring waste to be made more homogeneous at source. We could then generate more electricity, and build more value-adding industries. Legislation to mandate value addition with incentives for waste producers and resources such as tax incentives, land allocation for technology developers, along with enforcement to achieve maximum wood waste recovery should be made available to make high energy efficiency, capital intensive and long term investment biomass plants workable to secure the interest of investors and financial institutions. This approach has been highly successful to promote energy efficiency measures and is easily applied to waste management. Consider introducing acceptable standards for biomass power plants such as minimum system efficiencies to fully utilise the inherent energy from limited biomass fuel. In addition, authorities should allow other types of industrial waste to be used as supplementary fuel to the power plants to enhance energy efficiency and reduce the quantity of biomass required.	
	Tipping Fees The current waste model sets a cost of abatement through the tipping fee. This fee is based on the lowest cost of abatement but the technology alternative is not environmentally sustainable and is avoided in most other countries. Thus because the cost of disposing waste by tipping (cost of abatement) is low, it deters any further development of clean tech in this sector by making returns on investments unattractive.	Increase tipping fees Tipping fees should be increased and normalised to real cost of abatement which is much higher. This will spur local investment in biomass and biogas plants.	NEA
Planning	No common utility corridor infrastructure (steam/ chilled water/ cable) in energy intensive industrial parks	Provide piping for District Heating/Cooling Plants (DHCP) In order to maximise the plant efficiency and develop a feasible business model, supply of electricity, heat (steam) and chilled water is ideal. Support is needed from BCA / URA / JTC for the provision of common utility corridor infrastructure (steam/chilled water/cable) in energy intensive industrial parks, such as biomedical and wafer parks, in Singapore. With the above utility network available, both existing and new investors shall enjoy economic and social benefits (derived from economies of scale, sharing	BCA / URA / JTC

		of back up facilities, specialisation of services etc) via centralised biomass co/tri-gen plant.	
	No minimum/acceptable standards for biomass power plants such as minimum system efficiencies to fully recover the inherent energy from limited biomass fuel.	The supply of biomass waste is quite limited in Singapore, so NEA's policy of restricting wood and horticulture waste disposal in public incinerators increases the amount of waste available for biomass fuel and encourages investment in biomass power plants in Singapore. In view of the above, NEA should monitor & issue licences cautiously, to qualified biomass power plant operators, to ensure security of biomass fuel supply for such capital intensive and long term investments. Hence, consider introducing acceptable standards for biomass power plants such as minimum system efficiencies to fully recover the inherent energy from limited biomass fuel. In addition, allow other industrial waste to be used as supplementary fuel to the power plants to enhance energy efficiency and reduce the quantity of biomass required.	NEA
Guidelines for PV ready buildings	At the moment, the roofs of the buildings are not optimised, thus not leaving enough roof space for solar systems.	BCA can issue guidelines for building roofs to make them more compatible with solar PV. This is similar to design advice on building orientation to reduce solar heat gain and maximise natural ventilation.	BCA / URA / JTC
	Large percentages of buildings in Singapore are government owned, and not many have taken the lead to install renewable energy systems like solar.	Government buildings to lead the way in installing solar PV and tri-gen plants. HDB are already doing a wonderful job of promoting PV. Others can follow suit, for example JTC flatted factories, and MOE schools.	JTC / MOE
General	There is no one-stop-shop for the renewable energy industry.	EIPO should expand scope to bring awareness and engage with the industry like E2PO. Dedicated funding is needed to: ▪ Raise RE awareness and building capabilities ▪ Establishing an RE fund that could cover "state backed development or 'promotional' finance", such as German KfW low interest rate loans to RE projects from very small to very large scale. Local banks initially charge higher interest rates to cover their perceived risk, because they do not yet understand the low risk of RE projects, or do not know how to distinguish between high- and low-risk projects. Once the market develops, local banks develop experience and are	EIPO

		comfortable reducing their risk premiums. In the interim, a government fund can offer guarantees to reduce the banks' perceived risk and hence their interest rates. Lower interest rates lead to lower energy prices. This is not a subsidy, because the government fund is based on better understanding of the low risks inherent to RE projects.	
	Increasing demand for professionals with knowledge and skills in renewable energy engineering, design, installation, monitoring and maintenance. BCA's current ME03 work head does not currently specify any meaningful qualifications.	Encourage quality standards and workforce training, by specifying such qualifications as criteria to secure funding guarantees when financing projects (see above).	BCA / JTC / WDA / EIPO
	RE does not have a major role in the Singapore Green Agenda: Singapore has launched successful government-led green initiatives such as NEA's energy efficiency ratings on electrical appliances, the Solar Capability Scheme (SCS), the Market Development Fund (MDF), the Green Mark Scheme for buildings and the inclusion of RE in key master plans such as the Singapore Sustainable Development Blueprint issued in 2009. We also see much greater awareness, driven by the media covering green technology. However, despite the mentioned initiatives, RE is still not recognised as a significant component of the Singapore Green Agenda. The main gaps are: ▪ Lack of RE targets. Singapore does not have mandatory national renewable energy targets imposing retailers to source specific proportions of total electricity sales from RE sources according to a fixed timeframe. ▪ Lack of mandatory regulations to adopt RE in the building sector. The Green Mark was set up to stimulate the shift to green buildings in Singapore but it does not contain mandatory provisions.	A dedicated law to position RE in the Singapore Green Agenda The gaps should be fully addressed through the modification of existing laws such as the Electricity Act 2001 and/or a dedicated renewable energy law, including: ▪ Binding RE targets to meet a renewable energy percentage of the electricity fuel mix. RE should contribute to energy security as part of the mix of energy solutions being developed and implemented in Singapore. Furthermore, a mandatory rather than a voluntary framework creates a more credible environment to unlock capital markets to finance RE. ▪ Binding targets for planning authorities such as JTC to include a RE component when developing infrastructure projects. JTC and government buildings / facilities should lead by example and actively seek RE solutions for existing and pilot projects. ▪ Development of national RE roadmaps. ▪ Designation of a lead RE agency to monitor, implement and enforce the said law and other RE policies.	

The role of SEAS

The Sustainable Energy Association of Singapore (SEAS) represents the industry's interests to build a successful and competent clean energy sector in Singapore and the region.

The Clean Energy Committee within SEAS includes companies mainly involved in renewable energy technologies, of which solar photovoltaics is the most prominent, but biofuels, biomass and wind energy businesses are also members.

As an active contributor to facilitate the 2025 targets of this White Paper, SEAS will:

- Build awareness and know-how among the government and energy players of Singapore building & industry sector regarding the benefits and viability of RE through briefings, industry training and CEO roundtables.
- Facilitate cross border opportunities for RE through the organisation of dedicated business missions, trade fairs and project facilitation.
- Support innovative renewable energy companies both local and foreign to grow the ecosystem in Singapore by facilitating technology development, connecting to private capital & government grants.

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8. Glossary

Main power producers	Enterprises that produce electricity as their principal activity
Autoproducers	Enterprises that produce electricity typically for their own use, but for whom the production is not their principal activity
Contestable customers	Electricity consumers who are allowed to purchase electricity either from third-party retailers or the wholesale market
Non contestable customers	Consumers who can only buy electricity from the regulated service provider (SP Services). These are typically residential and small commercial consumers.
Grid Emission Factor (GEF), Average Operating Margin (OM)	GEF measures average CO_2 emissions per MWh of electricity. It is calculated using Average Operating Margin method, which is the generation-weighted average CO_2 emission per unit of net electricity generated by all power plants serving the grid.
Grid charges	What is paid to the utilities to recover the costs of transporting electricity through the grid.
Demand Response	Contractual arrangements that encourage consumers to curtail their electricity demand in response to pricing signals. Consumers shift some of their demand from peak to off-peak periods, thereby reducing peak electricity demand. See EMA's consultation paper: https://www.ema.gov.sg/media/com_consultations/attachments/508127e67a4c3-Demand_Response_Consultation_Paper_final.pdf
Interruptible load (IL)	Loads whose supply can be interrupted, providing reserve services to the grid. (IL reserve is an alternative to holding reserve on spinning part-loaded generators).
kWh	Kilowatt-hours. The basic billable unit of electricity 1kWh = 3'412 BTUs (British Thermal Units)
MWh, GWh, TWh	Megawatt-hours = 1'000 kWh Gigawatt-hours = 1'000 MWh Terawatt-hours = 1'000 GWh
MWe, MWth	Megawatt of electrical power Megawatt of thermal power
toe	Tonne of oil equivalent = the energy released by burning 1 tonne of crude oil 1 toe = 41.868 GJ = 11.63 MWh[12]
ktoe, Mtoe	kilo-tonnes of oil equivalent Mega-tonnes of oil equivalent = 1'000 ktoe
Cost of abatement	The cost of treatment or reduction of waste

[12] IEA/OECD definition. But the actual energy in 1 tonne of crude oil varies according to calorific value of the oil

Annex 1 - Redundant DC disconnects

The problem

Since mid 2011, SP Services and SP PowerGrid have been insisting on the addition of external DC disconnects at inverter inputs, regardless of whether the inverter already has properly rated DC disconnects built in.

DC disconnects are expensive, and this requirement for redundant external DC disconnects adds unnecessary cost to a PV system, as well as reducing reliability by introducing additional points of potential failure.

Detailed background

Singapore's CP5, as well as most international standards requires proper system design to include isolation for both AC and DC. See **Fig 14** below. Before disconnecting the DC side, one should first switch off the AC disconnect to remove the load. But the DC disconnect must still be able to handle improper disconnection under load. Its main function is to remove the load from the DC side, before any DC cables are unplugged.

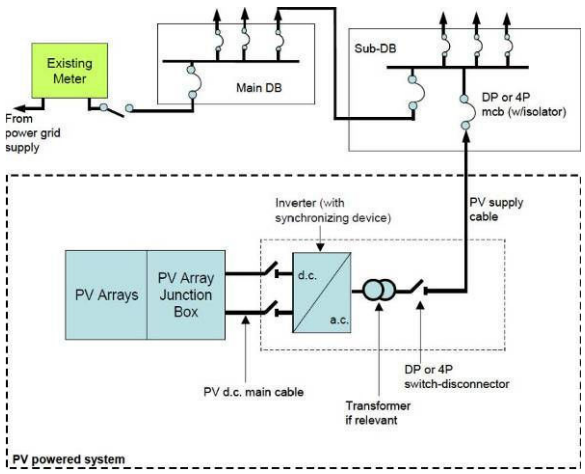

Fig 14 PV system diagram from EMA handbook

Properly rated DC disconnects are expensive and have long lead times. To help overcome this, as well as to prevent installers from skipping the installation of DC disconnects, most inverter manufacturers include a built in DC disconnect.

Opening the inverter's DC disconnect will disconnect the PV cables from any load and allow them to be safely unplugged from the inverter in case the inverter needs to be exchanged or overhauled.

Singapore's Code of Practice CP5 does not specify whether the DC disconnect must be external to the inverter or can be built in to the inverter. Up to mid 2011, SP Services and SP PowerGrid have accepted both arrangements on PV systems installed in Singapore.

Proposal

- To comply with CP5 and good industry practice, but without imposing unnecessary costs, external DC disconnects for string inverters should be mandatory only if the inverter has no adequate DC disconnects built in.
- Fully integrated devices like micro-inverters are connected directly to the PV module. A micro-inverter attached to the module frame or even integrated in the PV module's junction box turns the module into an AC generator. In this case, there should be no requirement for a DC disconnect, since it is highly impractical and of almost no use to insert a dc disconnect at every PV module.

Annex 2 - Grid charges

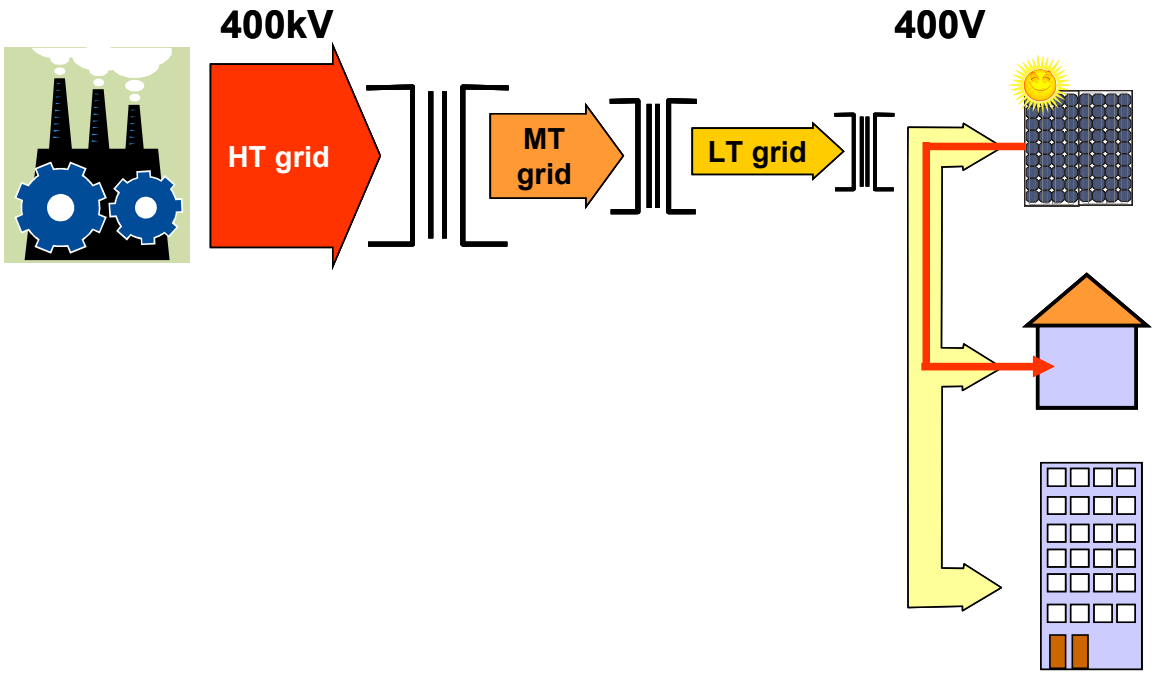

Fig 15 Surplus PV electricity exported to the grid only uses the "last mile" of the T&D infrastructure

Current grid charges of SGD0.0505/kWh assume amortising of the entire T&D infrastructure from Genco output to end consumer.

1. But exports from one building feed straight into the neighbouring building, making use only of the final roadside LV infrastructure. Hence they should not have to pay such high grid charges. SGD0.01/kWh is more justifiable to cover the use of the LV distribution section.
2. The precedent for lower grid charges already exists. HT consumers pay a much reduced grid charge of SGD0.01/kWh.
3. Further, since non-contestable customers pay a flat tariff 24/7 instead of a daytime peak and a night-time off-peak rate, they are effectively providing below-market electricity to the PowerGrid when they export PV electricity.
4. Similarly, all non-contestable customers pay too little for daytime electricity, in exchange for paying too much for night-time electricity. This cross-subsidy is hard to avoid.

We all recognise that many distortions are a consequence of the unjustified high cost to eliminate them, and accept a pragmatic compromise in dealing with them.

Currently, SP Services sources all its electricity from the Pool, adds a profit margin and a fee of SGD0.0505 for PowerGrid, and sells to non-contestable retail clients.

When SP Services absorbs PV electricity exported by a building, it pays the PV owner retail tariff minus Grid Charges or "T-G". The PV electricity is included in the mix that SP Services sells at retail tariff to the neighbouring building, for which it remits 5.05 cents/kWh to PowerGrid. Thus SP Services ends up remitting 5.05 cents for every kWh it sells.

If PowerGrid agrees to reduce grid charges to 1 cent/kWh, then SP Services needs to log separate grid charges for electricity it sources from the Pool and that sourced from PV exports.

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