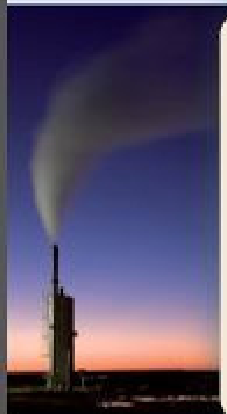

Sustainable Energy NOW
www.sen.asn.au

SEN W.A. 100% Renewable Energy on the SWIS 2029

8 February, 2013

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1. BACKGROUND AND OBJECTIVES

Sustainable Energy Now Inc. has been commissioned to provide a brief of scenario/s which demonstrate the potential for WA's SWIS electricity grid demand to be fully met by a combination of renewable energy generation, efficiency, storage and demand-side management within the SWIS grid, by 2029.

While this aim may be achievable, SEN recognises that there are practical limits with diminishing returns, to achieving this by a certain time, and that some forms of fossil generation may linger for various reasons, and/or be converted to use renewable fuels as feedstock.

There are various combinations of renewable energy and complementary technologies which could meet the objective, and SEN has been asked to provide at least one which is high in concentrated solar thermal (CST) generation, with other possible scenarios as options. This report has used the SEN Renewable Energy Simulation to assist in modelling the scenarios, however, this software has limited capabilities and has not been independently checked and is therefore only intended as an illustration to aid in visualisation.

The option of a high voltage DC interconnector to the NEM grid in the Eastern States has not been considered in this report.

It should also be noted that 'fully renewable" does not mean 'zero carbon' as even the technologies here have embodied emissions factors, albeit low (<0.06 kg CO_2e / kWh) compared to coal fired electricity emission factors (> 1.0 kg CO_2e / kWh).

This study is a preliminary desktop investigation of the options, due to limited time. In particular, a detailed analysis of wind and solar data across the SWIS grid data was not conducted for this study and is required to determine the amount of biomass fired and other backup energy needed to cover periods of low wind speed and low solar radiation. Levelised costs of electricity and other parameters have been estimated by ratioing capacity factors of the various technologies against rated (maximum) capacity factors from references and shown in tables 1, 2 and 3. Due to the number of assumptions and projections both in this study and referenced studies, the information presented should be considered only approximate, for visioning and discussion purposes.

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2. EXECUTIVE SUMMARY

2.1 WA has among the best solar, wind and wave resources in the world and the potential to generate renewable energy from these resources is enormous.

2.2 A number of SWIS grid scenarios were investigated for this report summarised as:

- Scenario 1 Solar thermal dominant with backup biomass at solar CST plants;
- Scenario 2: Lower cost diverse mix with wind and solar PV dominant;
- Scenario 3: Business as Usual (BAU) without Carbon Capture and Storage or efficiency/waste reduction gains, following the fossil growth philosophy of the state government's Energy 2031 Strategic Energy Initiative as the basis.

Costs for generation, storage and transmission are summarised in the Tables 1 – 3.

2.3 If the existing fossil fuelled grid is retained in a (BAU) case (Scenario 3), capital investment excludes the cost of any form of Carbon Capture and Storage (CCS), should it become viable, nor does it include, due to increased demand, that it is likely that an additional gas pipeline will be required to deliver gas to generators near Perth to satisfy this. Rising coal and gas prices, and to a lesser extent the price on carbon, will make fossil generation more expensive.

While renewable scenarios will require more capital expenditure than adapting the existing fossil fuelled grid, it will ultimately provide energy at less cost because technology costs of renewables are decreasing and there are no fuel costs, except for biomass. For example the Australian Energy Technology Assessment (AETA) has forecast the Levelized Cost of Electricity (LCOE) from new wind, biomass and solar PV power plants to be lower than generation from new coal fired plants even without being equipped with CCS while the cost of solar concentrated thermal with storage is likely to be only slightly more. (Ref: Australian Bureau of Resource and Energy Economics (BREE) "Australian Energy Technology Assessment).

2.4 The absence of interconnection with the NEM grid and the need for rotating generators that can control network voltages and frequency results in the requirement for a small amount of biomass-fuelled backup generation combined with pumped-hydro storage during times of low solar irradiance and wind velocity.

2.5 SEN scenarios outlined in the tables below utilise LCOE and capital costs adapted largely from; BREE *Australian Energy Technology Assesment (AETA)* 2012, Melbourne Energy Inst., 2011. *Renewable Energy Technology Cost Review 2011*.

2.6 Significant 'over-build' of wind, solar and biomass generation is included so that the proposed scenarios should provide sufficient dispatchable backup and storage for up to 3 consecutive days 4 times per year of coinciding minimal solar and wind conditions throughout the SWIS area. However, more widespread, detailed analysis of wind and solar records is required to confirm this assumption.

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Table 1.

Senario 1: Solar CST dominant								
Technology	Power capacity, MW 2029	Est. Energy GWh /yr	Cap. cost $/kW' (BREE, 2012 & ZCA 2010)	New plant cap. cost $bn	Rated capacity factor (CF)	LCOE $/MWh at rated CF	Est.(CF) for scenario***	LCOE at scenario CF
Wind	**2,500**	6,242	$2,530	$6.3	0.38	$91	0.29	$121
Solar CST + storage	**3,500**	9,658	$8,308	$29.1	0.42	$187	0.32	$249
Solar PV large tracking + rooftop	**1,300**	2,050	$3,860	$5.0	0.24	$147	0.18	$196
Biomass backup (Solar CST co-firing + Collie/Kwinana)****	**2,800**	2,453	$500	$1.4	0.80	$89	0.10	$299
Wave	**500**	1,150	$5,900	$3.0	0.35	$222	0.26	$296
Geothermal	**300**	1,636	$7,000	$2.1	0.83	$156	0.62	$208
TOTAL & Weighted Average Levelized Cost of Energy $/MWh	**10,900**	**23,188**		**$46.9**		**$147**		**$215**
Pumped storage hydropower* (Assume servicing 50% of wind energy)	**500**	3,121	2,500	**$1.3**	0.80	$86	0.80	$86
Total Generation + Pumped Hydro				**$48.1**				
Weighted Average Levelized Cost of Energy (incl Pumped Hydro) $/MWh**						**$151**		**$221**
Storage solar CST	**3500**	**n/a**	**n/a**	**n/a**				

*Note: Pumped hydro ref for Capital Cost & LCOE: NREL, 7% discount rate. Cost of lower pond is minor factor.

**LCOE increased by the ratio of: total capital with pumped hydro / capital without pumped hydro.
*** LCOE's for this scenario are based on CF which is 75% of the CF at rated LCOE (excluding biomass which is the minimum considered necessary for backup/reserve).

**** Capital portion of LOCE assumed as 50% of full biomass plant. Therefore LCOE = (fuel cost+ratio of CFs x (capital component of LCOE-fuel component of LCOE). Fuel component is $ 59/MWh.

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Table 2.

Senario 2: Lower-Cost, Wind and PV Dominant								
Technology	Power MW capacity 2029	Est. Energy GWh /yr	Capital cost $/kW (BREE, 2012)	New plant cap. cost $bn	Rated capacity factor (CF)	LCOE $/MWh at rated CF	Est. CF for scenario***	LCOE at scenario CF
Wind	3,000	7,789	$2,530	$7.6	0.38	$91	0.30	$117
Solar CST + storage	1,500	4,305	$8,308	$12.5	0.42	$187	0.33	$240
Solar PV large tracking + rooftop	3,000	4,920	$3,860	$11.6	0.24	$147	0.19	$188
Biomass backup (Co-firing)****	2,500	3,285	$500	$1.3	0.80	$89	0.15	$219
Wave	500	1,196	$5,900	$3.0	0.35	$222	0.27	$285
Geothermal	300	1,701	$7,000	$2.1	0.83	$156	0.65	$200
TOTAL GENERATION	10,800	23,196		$37.9		$132		184
Pumped storage hydropower*	2,000	3,895	2,500	$5.0	0.80	$86	0.80	$86
Total Generation + Pumped Hydro				$42.9				
Weighted Average Levelized Cost of Energy $/MWh**						$149		$208
Storage solar CST	1500	n/a	n/a	n/a				

*Note: Pumped hydro ref for Capital Cost & LCOE: NREL, 7% discount rate. Cost of lower pond is minor factor.

**LCOE increased by the ratio of: total capital with pumped hydro / capital without pumped hydro.

*** LCOE's for this scenario are based on CF which is 78% of the CF at rated LCOE (excluding biomass which is the minimum considered necessary for backup/reserve).

**** Capital portion of LOCE assumed as 50% of full biomass plant. Therefore LCOE = (fuel cost+ratio of CFs x (capital component of LCOE-fuel component of LCOE). Fuel component is $ 59/MWh.

Note: The CF's in the above tables are low because of the 'overbuild' of installed capacity and storage needed to meet the few low solar & wind energy events through the year.

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Table 3.

'Business as usual' per SEI2031 SWIS (Replace and expand existing fossil plant) Without: CCS, Effic/Waste gains									
Replacem't Technology	**Power capacity 2012, MW**	**Power Capacity est. 2029 (1.47x 2012x1.15), MW**	**Est. Energy GWh /yr 2029**	**Capital cost $/kW (BREE AETA)**	**Replacem't plant cost ($bn)**	**Rated capacity factor (BREE AETA)**	**LCOE $/MWh at rated CF* (BREE AETA)**	**Est. CF for scenario**	**Est. LCOE $/MWh, scenario CF*** **
Coal supercritical (No CCS)	2,317	3,916	20,879	$3,381	$13.2	0.83	$166	0.70	197
Combined cycle gas (No CCS)	274	463	2,116	$1,111	$0.5	0.83	$137	0.60	190
Open cycle gas (No CCS)	2,399	4,054	3,088	$723	$2.9	0.1	$253	0.10	253
**Other - IC (est costs scaled up from CCG) ** **	2	3	16	$800	$0.0	0.83	$137	0.80	142
TOTAL	4,992	8,436	26,101		$16.7				
Weighted average levelized cost of energy (LCOE)									**$203**

**Note : All LCOE (levelized cost of energy) figures assume a carbon price*
*** Capital cost estimated.*

**** Proportional to ratio of Rated and Estimated CFs. "Variable costs" difference is small because CFs are similar.*

Summarising the 3 tables above:

	Avg. LCOE, $/MWh	Generation Capital Cost, $bn	Other Capital Cost, $bn	Transmission Capital Cost, $bn
Scenario 1 Renewables - CST dominant	221	46.9	1.3	14
Scenario 2 Renewbles - Lower cost wind and PV dominant	205	37.9	5	14
Scenario 3 BAU, Replace/expand fossil generation	203	16.7	Gas supply system to SWIS generators (pipeline or other)	3.9

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3. ELECTRICTY DEMAND IN 2029

Assumptions:

- The W. Australian Strategic Energy Initiative 2031 Directions Paper May 2011, projects electrical energy growth of 2.3%/yr. (Derived from electricity growth of 57% over 20 years).
- For the renewable energy scenarios, it is assumed that efficiency gains, waste reduction and displacement of electricity by direct solar water and space heating and geothermal 'Hot Sedimentary Aquifer' (HSA), reduces the rate of energy growth by 30%, resulting in a 1.6%/yr actual growth. Therefore it is assumed that demand reaches 23,000 GWhr/yr (23 TWh/yr) in 2029. (An overall increase of 31%).
- For the non-renewable energy scenario 3 (BAU) it is assumed that no gains in efficiency or waste reduction occur, resulting in a 2.3%/yr electricity growth, reaching 26,000 GWh (26 TWh) in 2029. (An overall increase of 47%).
- Plug-in Hybrid Electric Vehicles (PHEV) and Electric Vehicles (EV) increase demand negligibly by 800 GWhr/yr (0.8 TWh/yr). (Note 1)
- Electric Metro/light rail increases demand negligibly by 0.075 TWhr/yr (Note 2)

Notes:

1. PHEVs and EVs are assumed to reach 10% of the total WA passenger vehicle fleet by 2029. (See appendix for calculations). Power draw from PHEVs/EVs could be in the order of 1.2 GW if all were on a 4kW charge rate over an average of 2 hr; however this can be reduced by load shifting to a large extent as trials indicate most owners charge at home. In this case the load could be reduced to say 300MW over 8 hr overnight, and/or distributed over low demand periods in the day, so that peak demand is not increased
2. Capacity & size similar to Melbourne's Yarra Trams in 2009. (See appendix for calculations)

The average and peak power demand on the SWIS for the Renewable Energy Scenarios is shown in the figure below.

Figure 1. WA SWIS 2029 Load Demand Scaled Up from 2012 at 1.6%/yr, MW