
Distributed Energy Systems - Constant Energy in a World of Constant Change

Warner Priest – Emerging Technologies
Siemens Australia
Decarbonization of the global economy by 2100 will require a multi-faceted solution set

Policy is forcing worldwide decarbonization

G7 summit, 2015: Decarbonization of the global economy by 2100: Greenhouse gas emission reductions of 40% to 70% by 2050 (baseline: 2010)

COP21, 2015: 195 countries adopt the first universal climate agreement: This to keep the global temperature rise this century well below 2°C

COP23, 2017: 197 Parties discussed how and to what extent they can implement decarbonization measures

renewable installations are increasing

Global Wind Installations (GW)

Global Solar PV Installations (GW)

but CO₂ emissions have stagnated

Global CO₂ Emissions (Gt)

Sources: 1) IRENA, Renewable Capacity Statistics 2017; 2) IEA

So what can we expect going forward?

► More renewables integration
► Decarbonization of all industry
► Changes in legislation
Mining Operations have Traditionally been Grid Connected – Electrical Grid - Centralized Gen or Gas grid - onsite Gen

**Electrical Grid Connected Centralized Generation**

- Fossil power plant
- Transmission Substation
- 132kV Transmission Line
- 35MW Total Load
- Mine Processing Ore Facility
- Distribution Substation
- Mine Winder
- Crusher
- Distribution Substation
- Water Treatment Facility
- Waste Water
- 25MW Load
- 10MW Load
- Conveyor Belt Load
- Excavator Load
- Prime Mover / Ore to Port
- Diesel Truck

**Gas Grid Connected On-site Generation**

- Natural Gas / Diesel Pipeline
- 35MW Total Load
- Mine Processing Ore Facility
- Distribution Substation
- Mine Winder
- Crusher
- Distribution Substation
- Water Treatment Facility
- Waste Water
- 25MW Load
- 10MW Load
- Conveyor Belt Load
- Excavator Load
- Prime Mover / Ore to Port
- Diesel Truck

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Hybrid Power Plants based on renewables are now reality
Wind & PV Power + Battery Storage and Digitalization

- A Diesel or Gas On-site Power plant serving a 35MW load CAPEX ~$25M to $43M.
- The OPEX cost for the Diesel or Gas Fuel only over 20 years ~$1.2B to ~$1.4B.
- By integrating renewables, (CAPEX of ~$130M), ~70% of the fuel cost over 20yrs could be offset (Wind & PV).
- Reducing reliance on fossil fuel, could be the difference between a mine being commercially viable or not.
- Shifting mining operations to only the hours of renewable generation, fossil fuel use is reduced further.

.............there are further considerations to take into account
Hydrogen Hybrid Power Plants – Potential to go 100% renewables
Wind & PV Power + Battery / H₂ Storage and Digitalization

- For a Hybrid Power plant based on Wind and Solar PV ~15% of the potential generated energy per year would need to be spilled.
- This spilled energy could be absorbed by large utility scale PEM Electrolyzers to produce on site hydrogen.
- Hydrogen has many value streams; it is a energy dense fuel that can be stored and then re-electrified.
- Hydrogen can be used as a fuel for heavy haulage FCEV trucks.
- Hydrogen could be used for ammonia production for mineral processing / Ammonia leaching
So what next? This is where the digital journey begins - PSS®DE – One software environment for the entire DES design process

Generation and Control

<table>
<thead>
<tr>
<th>Configuration 1</th>
<th>Configuration 2</th>
<th>...</th>
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</thead>
<tbody>
<tr>
<td>PV</td>
<td>-</td>
<td>25 MW</td>
</tr>
<tr>
<td>Wind</td>
<td>65 MW</td>
<td>60 MW</td>
</tr>
<tr>
<td>Storage</td>
<td>-</td>
<td>10 MW (3 MWh)</td>
</tr>
<tr>
<td>Diesel</td>
<td>50 MW</td>
<td>50 MW</td>
</tr>
</tbody>
</table>

Power System Study and Dynamic Study

Techno-Economic Performance

How to integrate?

- Geographical map
- Network diagram
- Load density

Tool 1

Tool 2

Manual

PSS®DE
1. General
   a) Project commencing 2023
   b) Initial load profile of 30MWave, 35MWp
   c) 15 year mine life, load increase in future not considered
   d) Load profile based on a synthetic load generated for modelling some load variability
   e) Solar PV based on initial evaluation output from PVsyst, assuming a 1st year yield with single axis tracking of 2,188kWh/kWp, and 0.35% degradation each year
   f) Wind generation based on assumed wind speed data of average 7.42m/s, and assuming a 6% average degradation per turbine for the unknown wake factor

2. Scenarios
   a) Reference [0] based on diesel generation only

3. Financial Parameters:
   a) Target ROE: 14%
   b) Company Tax Rate: 30%
   c) WACC: 7.13%
   d) Debt Repayment Period: 15 years
   e) Debt Interest rate: 6.0%
   f) Gearing: 30 / 70

4. Project Term: 20 years
5. Escalation of fuel: 2.5% p.a
7. Energy/Fuel Prices:
   a) Diesel Fuel: $0.78/L + $0.30/L delivery charge

8. Environmental Incentives
   a) ACCUs at $15/tonne, with reduced LCOE shown

9. No GST considered

10. Note that displacing Diesel Fuel for road transport $1.50/L (not part of study)
2 – Simulation Cases: Configurations analysed

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<thead>
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<tbody>
<tr>
<td><strong>Comparison</strong></td>
<td>Diesel</td>
<td>Hybrid Power Plant (Wind)</td>
<td>Hybrid Power Plant (Wind &amp; Solar)</td>
<td>Hybrid Power Plant (Solar)</td>
<td>Hybrid Power Plant (Wind &amp; Hydrogen)</td>
</tr>
<tr>
<td><strong>Fossil (diesel / CNG)</strong></td>
<td>38.25MW</td>
<td>38.25MW</td>
<td>38.25MW</td>
<td>38.25MW</td>
<td>35.35MW</td>
</tr>
<tr>
<td><strong>Solar PV (dc)</strong></td>
<td>-</td>
<td>-</td>
<td>17MWp</td>
<td>40MWp</td>
<td>17MWp</td>
</tr>
<tr>
<td><strong>Wind</strong></td>
<td>-</td>
<td>42MWp</td>
<td>42MWp</td>
<td>-</td>
<td>42MWp</td>
</tr>
<tr>
<td><strong>BESS</strong></td>
<td>-</td>
<td>12MW 4MWh</td>
<td>12MW 4MWh</td>
<td>12MW 4MWh</td>
<td>12MW 4MWh</td>
</tr>
<tr>
<td><strong>SILYZER (H₂ production)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Fuel Cells (H₂)</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</table>
### 3 – Results: Overview on simulation results

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<td>Hybrid Power Plant (Wind)</td>
<td>Hybrid Power Plant (Wind &amp; Solar)</td>
<td>Hybrid Power Plant (Solar)</td>
<td>Hybrid Power Plant (Wind &amp; Hydrogen)</td>
</tr>
<tr>
<td>CAPEX MAU$</td>
<td>25.6</td>
<td>111</td>
<td>135</td>
<td>90</td>
<td>153.5</td>
</tr>
<tr>
<td>OPEX 1 year MAU$</td>
<td>9.1</td>
<td>5.5</td>
<td>5.15</td>
<td>7.6</td>
<td>6.2</td>
</tr>
<tr>
<td>Replacement MAU$</td>
<td>11.5</td>
<td>5.7</td>
<td>5.15</td>
<td>7.6</td>
<td>7.5</td>
</tr>
<tr>
<td>LCOE AU$/kWh</td>
<td>0.380</td>
<td>0.237</td>
<td>0.223</td>
<td>0.323</td>
<td>0.230</td>
</tr>
<tr>
<td>ACCU value/year* MAU$</td>
<td>0.00</td>
<td>1.277</td>
<td>1.486</td>
<td>0.654</td>
<td>1.577</td>
</tr>
<tr>
<td>LCOE w. ACCU applied AU$/kWh</td>
<td>0.380</td>
<td>0.234</td>
<td>0.220</td>
<td>0.322</td>
<td>0.226</td>
</tr>
</tbody>
</table>

* Application of ACCUs, at $15/tCO2 avoided, is applied against modelled emissions data (Australian Carbon Credit Units). See next slide for details.
### 3 – Results: Overview on simulation results

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<tr>
<td><strong>Comparison</strong></td>
<td>Diesel</td>
<td>Hybrid Power Plant (Wind)</td>
<td>Hybrid Power Plant (Wind &amp; Solar)</td>
<td>Hybrid Power Plant (Solar)</td>
<td>Hybrid Power Plant (Solar, Wind &amp; Hydrogen)</td>
</tr>
<tr>
<td><strong>Wind Share %</strong></td>
<td>-</td>
<td>58.23</td>
<td>58.26</td>
<td>-</td>
<td>58.26</td>
</tr>
<tr>
<td><strong>Solar Share %</strong></td>
<td>-</td>
<td>-</td>
<td>9.52</td>
<td>29.92</td>
<td>9.52</td>
</tr>
<tr>
<td><strong>Fuel Cell Share %</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3.60</td>
</tr>
<tr>
<td><strong>Renewable Share %</strong></td>
<td>-</td>
<td>58.23</td>
<td>67.78</td>
<td>29.92</td>
<td>71.38</td>
</tr>
<tr>
<td><strong>Diesel Used (per year)</strong> MAU$</td>
<td>64.45</td>
<td>27.0</td>
<td>21.05</td>
<td>45.35</td>
<td>19.05</td>
</tr>
<tr>
<td><strong>Diesel Fuel ML per year</strong></td>
<td>55.65</td>
<td>23.45</td>
<td>18.2</td>
<td>39.15</td>
<td>16.45</td>
</tr>
<tr>
<td><strong>Carbon Emissions t CO₂ per year</strong></td>
<td>147,188</td>
<td>62,028</td>
<td>48,101</td>
<td>103,567</td>
<td>41,993</td>
</tr>
</tbody>
</table>
3 – Hydrogen Production

Operating Constraints

- 17.5MW SILYZER (8.75MW block scalable up to 17.5MW)
- 20-100% operating range (3.5MW – 17.5MW)
- 350kg/h Hydrogen produced, nominal rating at full load (0.02kg/kWh)
- Operation restricted to daylight hours & excess Solar PV available

Comparison

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Hybrid Power Plant (Wind &amp; Hydrogen)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Production t/year</td>
<td>577.5</td>
</tr>
<tr>
<td>Energy from Wind GWh</td>
<td>28.85</td>
</tr>
<tr>
<td>Energy from Solar GWh</td>
<td></td>
</tr>
<tr>
<td>H₂O required ML Potable / Demineralised</td>
<td>9.65 / 5.8</td>
</tr>
</tbody>
</table>
## 3 – Fuel Cell Generation

### Operating Constraints

- 1.5MW Fuel Cell Used
- Efficiency modelled at 49% at all operating ranges
- Qty based on actual available H₂ production from SILYZER

<table>
<thead>
<tr>
<th>Scenario [45]</th>
<th>Comparison</th>
<th>Hybrid Power Plant (Wind &amp; Hydrogen)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>No. of Fuel Cells</strong> Units (1MW)</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen Production</strong> t/year</td>
<td>577.5</td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen Consumption</strong> t/year</td>
<td>552.5</td>
<td></td>
</tr>
<tr>
<td><strong>Excess Hydrogen</strong> t/year</td>
<td>25</td>
<td></td>
</tr>
</tbody>
</table>
4 – PSSDE Output

Actual Mine
Synthetic load Profile, 1 year, 1 minute interval
32,815kWp
26,197kWave
251.35GWh

Actual Mine
Synthetic load Profile, 7 days shown
PSSDE Output Modelling result for a 35MW Mining Load

Scenario XX – HPP with H₂
All major components
7 days

Scenario 45 – HPP with H₂
H₂ fuel cell & Diesel generation
7 days

Scenario 45 – HPP with H₂
SILYZER H₂ production & renewable 'curtailed' energy
7 days
Silyzer 300 –
the next paradigm in PEM electrolysis

17.5 MW
per full Module Array
(24 modules)

75 %
System efficiency
(higher heating value)

24 modules
to build a
full Module Array

340 kg
hydrogen per hour
per full Module Array
(24 modules)
## Silyzer 300 Fact Sheet

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen production</td>
<td>100-2,000 kg/h</td>
</tr>
<tr>
<td>Plant efficiency (HHV(^1))</td>
<td>&gt; 75 %</td>
</tr>
<tr>
<td>Start up time</td>
<td>&lt;1 min, enabled for PFRS(^2)</td>
</tr>
<tr>
<td>Dynamics in range</td>
<td>10%/s in 0-100%</td>
</tr>
<tr>
<td>Minimal load</td>
<td>20% single module</td>
</tr>
<tr>
<td>Nominal plant footprint</td>
<td>70 MW/1,300 kg/h H(_2); 70x25m</td>
</tr>
<tr>
<td>System lifetime</td>
<td>&gt; 20 a (Module ≈ 10 a)</td>
</tr>
<tr>
<td>Plant availability</td>
<td>~ 95 %</td>
</tr>
<tr>
<td>Demin water consumption</td>
<td>10 l/kg H(_2)</td>
</tr>
<tr>
<td>Dry gas quality(^3)</td>
<td>&gt; 99.9 H(_2); &gt; 99.5 O(_2)</td>
</tr>
<tr>
<td>Delivery pressure</td>
<td>customized</td>
</tr>
</tbody>
</table>

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1) Plant efficiency includes rectifier, transformer, transformer cooling and gas cooling
2) Primary Frequency Response Service
3) w/o DeOxo

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Page 16
The modular design of Silyzer 300 can be easily scaled to your demands

<table>
<thead>
<tr>
<th>Module</th>
<th>Module array</th>
<th>Customized solution</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Between 12 and 24 modules</td>
<td>n+1</td>
<td>Scale up to the necessary demand</td>
</tr>
</tbody>
</table>

Modular concept to cover wide production rate
Silyzer 300 layout optimized for small footprint but still service friendly

Sample plant layout: 70 MW / 1,300kg/h H₂

- **Maximum operational flexibility:**
  Two separate 35 MW buildings with up to 8 individually dispatchable electrolyzer rows each

- **Fast and effective service and maintenance:**
  6 easy-to-access and easy-to-replace PEM modules per electrolyzer series

- **Small & cost effective footprint:**
  Standard industrial buildings (optional rooftop cooling on steel structures), optimized piping and cabling

- **Main building requirements:**
  - **Minimum height:** At least 5m high
  - **Minimum Indoor Temperature:** Frost protection: +5°C at the lowest point
  - **Maximum Indoor Temperature:** +40°C
  - **Ex-zone:** Since all systems are hydrogen sealed, no need for the ex-zone inside of the building

![100 x 25 m layout](image1.png)

![70 x 25 m layout w/ rooftop cooling](image2.png)
Mainz Energie Park in service since mid 2015 - Power-to-Gas project in Germany
Siemens Hydrogen electrolysis – facts and figures Silyzer 200

5 MW
World's largest operating PEM electrolysis system in Hamburg, Germany

60 kWh
Specific energy consumption for 1 kg hydrogen

20 kg
Hydrogen production per hour

1.25 MW
Rated stack capacity, peak power 2 MW

H&R GmbH & Co. KGaA inaugurates world's largest dynamic hydrogen electrolysis plant

24 November 2017

H&R Ölwerke Schindler, a subsidiary of H&R GmbH & Co. KGaA, has inaugurated the world's largest dynamic hydrogen electrolysis plant based on PEM technology. "Dynamic" means that the hydrogen electrolysis plant can take advantage of last-minute surges in electricity production, i.e. from wind turbines, to produce hydrogen. The centerpiece of the €10-million plant is a Siemens-built electrolyzer with 5 MW of electric capacity. The plant will produce several hundred tons of hydrogen per year, which will be used as a resource in refinery processes.

Construction starts at the world's largest hydrogen pilot plant

Munich/Linz, 2018-Apr-16

- World's largest pilot plant for the production of "green" hydrogen at the voestalpine site in Linz, Austria
- Capacity of 6 megawatts: the most effective and advanced plant of its type
- Plant is scheduled to be fully operational by spring 2019

An EU-funded flagship project for a CO2-reduced energy future and the decarbonization of steel production is taking shape: today, at the voestalpine site in Linz, the H2FUTURE project consortium, consisting of voestalpine, Siemens, VERBUND, and Austrian Power Grid, together with the research partners K1-MET and ECN, officially gave the go-ahead for construction of the world's largest pilot plant for the production of "green" hydrogen. With a capacity of 6 megawatts, this is the most effective and advanced plant of its type. The partners from industry and power generation will use this facility to research into future breakthrough technologies which are needed to meet global climate goals over the long-term. The plant is scheduled to be fully operational by spring 2019.
Tonsley Park Precinct MicroGrid in Adelaide to build Hydrogen Demonstration Plant.

Australian-first, $11.4 million hydrogen demonstration plant to be built in Adelaide

An Australian-first, $11.4 million demonstration plant that will produce hydrogen from renewable energy will be built in Adelaide.

Adelaide-based Australian Gas Infrastructure Group (AGIG) – the country’s largest gas distribution business – will construct and operate the state-of-the-art plant at Tonsley Innovation District, in Adelaide’s southern suburbs.

This follows a $4.9 million grant from the South Australian Government through its $150 million Renewable Technology Fund.

The power-to-gas demonstration plant – to be called Hydrogen Park SA (HyP SA) – will produce hydrogen from renewable electricity, which will then be injected into the local gas distribution network at the Tonsley Innovation District south of Adelaide to provide low-carbon gas to homes and businesses.

“We are delighted that South Australia will lead the way with this pioneering technology,” AGIG Chief Customer Officer, Mr Andrew Stanford, said today.

“The aim of the demonstration plant is to reflect how energy will be provided to businesses and homes in the future,” he said.

“It will also illustrate the complementary nature of gas and electricity in meeting the decarbonisation challenge – a key in balancing the energy triadle.

The groundbreaking project will involve the construction of a hydrogen production and distribution facility using a 1.25MW PEM electrolyser to produce hydrogen utilising electricity from the grid and potentially on-site solar.

The produced hydrogen will then be injected into AGIG’s local gas network to power the Tonsley Innovation District – but with the ability to be expanded to supply a proposed residential development in the area and other remote customers through tube and trailer facilities.

Mr Stanford said key features of the pilot plant include it:

- being one of the largest PEM electrolyzers in Australia;
- is expected to be Australia’s first integrated hydrogen-electricity-gas project;
- involves SA-based energy leaders working together;
- decarbonises gas supply including a green-gas residential development;
- provides for a hydrogen Centre of Excellence facilitating education, training, research and engagement, and;
- expediting research and development which will inform and accelerate a commercial hydrogen economy.

AGIG’s project partners are Siemens, SA Power Networks and KPMG.

Siemens Australia Chairman and CEO, Mr Jeff Connolly, said: “Hydrogen holds exciting potential for Australia, and it’s great to be partnering with the South Australian government and Australian Gas Infrastructure Group delivering proven and world leading hydrogen technology.

“It’s pleasing to see hydrogen become reality since we began driving this conversation in Australia only a few short years ago,” he said.

“By reticulating hydrogen into the gas network it supports de-carbonisation of the state. It also supports the development of a domestic market for hydrogen which I believe can lead to Australia becoming a world energy superpower if we harness the untapped renewable assets of the country.”
Questions

Mr. Warner Priest
BDM Emerging Technologies
EM Division
160 Herring Rd Macquarie Park; NSW
Phone: +61 (0)2 9491-5613
Mobile: +61 (0)428 565753
Customer Care: 1300 668 336
E-mail: warner.priest@siemens.com