1.1 Solar Thermal Panels Plant pre-feasibility study

In this early pre-feasibility study the installation of a highly efficient solar district heating plant consisting of flat plate collectors is considered. Until now, there is many successful solar power plants around the world but this would be the first stand-alone solar panel field connected to the UB District Heating network, and could become a step forward to green district heating facilities introduction in Ulaanbaatar city.

The pre-study suggested in the long term investment plan should allow investigating the potential to utilize solar heating to reduce the Ulaanbaatar district heating plant’s lignite dependency and severe air pollution. The biggest challenge could be to determine the location of such an installation.

As an inspiration, the consultant considered 10 MW Solar Thermal Panels Plant. The assumed flat plate collector’s optical efficiency is 80% with heat loss coefficient 3.0 W/m²/K

In the pre-study two possible output temperatures 60°C and 80°C were considered.

The weather data used including insolation are Mongolia specific.

1.1.1 Supply temperature of 60°C

In the below graph the collector field yield is presented in red for the month of February. Despite the average outdoor temperatures in that period is below zero at all times, the clear sky allows for daily peak of up to 7kW from each 10m² of solar panels.

![Figure](Error! No text of specified style in document.)-1 Weather data and collector field yield during the month of February, location Mongolia, for 10m² collectors area and slope of 60deg.
In the month of June less peak production is expected comparing to winter months.

Based on above data the consultant calculated the monthly heat production capacity for each m² of collector’s area.
Heat production capacity for 60°C

<table>
<thead>
<tr>
<th>Month</th>
<th>kWh/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>52.6</td>
</tr>
<tr>
<td>February</td>
<td>71.5</td>
</tr>
<tr>
<td>March</td>
<td>91.7</td>
</tr>
<tr>
<td>April</td>
<td>71.2</td>
</tr>
<tr>
<td>May</td>
<td>67.4</td>
</tr>
<tr>
<td>June</td>
<td>55.7</td>
</tr>
<tr>
<td>July</td>
<td>59.5</td>
</tr>
<tr>
<td>August</td>
<td>62.9</td>
</tr>
<tr>
<td>September</td>
<td>69.5</td>
</tr>
<tr>
<td>October</td>
<td>84.8</td>
</tr>
<tr>
<td>November</td>
<td>58</td>
</tr>
<tr>
<td>December</td>
<td>46</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>790.8</strong></td>
</tr>
</tbody>
</table>

Table *Error! No text of specified style in document.*-1 Monthly heat production with supply temperature of 60°C

*Note:* The highest heat production may be achieved in March with approx. 91.7 kWh for each m². To be able to produce that amount of heat, the average heat production per m² in March is in the magnitude of 0.12 kW.

As observed at the Figure *Error! No text of specified style in document.*-3 presenting the yearly collector field yield, the peak production in March and October is around 0.81 kW/m². Consequently the required panel's area for 10 MW Solar Thermal Panel Plant should be of around 12,350 m². To be able to utilize the panel's capacity to the maximum the proper Mongolia specific angle and distance between panels should be maintained. For panel's installation purposes, usually a land area three times larger than the panel area is assumed. In this case it would have to be an area of approx. 3.70 ha.

The expected yearly production of heat with 60°C supply temperature is in the magnitude of 8,390 Gcal.
### Output supply temperature 60°C

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>March production per 10 m²</td>
<td>917 kWh/10m²/March</td>
</tr>
<tr>
<td>March production per 1 m²</td>
<td>91,7 kWh/m²/March</td>
</tr>
<tr>
<td>Maximum production per m²</td>
<td>0,810 kW/m²</td>
</tr>
<tr>
<td>10 MW production collector’s area required</td>
<td>12 346 m²</td>
</tr>
<tr>
<td>10 MW production collector’s area required</td>
<td>1,23 ha</td>
</tr>
<tr>
<td>Assessed land required</td>
<td>3,70 ha</td>
</tr>
<tr>
<td>Yearly output for 10MW solar plant</td>
<td>9 753 MWh/year</td>
</tr>
<tr>
<td>Yearly output for 10MW solar plant</td>
<td>8 388 Gcal/year</td>
</tr>
<tr>
<td>CO2 emission avoided</td>
<td>11 616 tCO₂/year</td>
</tr>
<tr>
<td>CAPEX solar panels</td>
<td>2 784 740 USD</td>
</tr>
<tr>
<td>CAPEX heat storage tank, 3000m3</td>
<td>655 236 USD</td>
</tr>
<tr>
<td>CAPEX grand total</td>
<td>3 439 975 USD</td>
</tr>
<tr>
<td>OPEX</td>
<td>139 237 USD/Year</td>
</tr>
</tbody>
</table>

Table **No text of specified style in document**. Main estimated figures for 10 MW Solar plant installation in Ulaanbaatar with temperature output of 60°C

#### 1.1.2 Supply temperature of 80°C

In the below graph the collector field yield is presented in red for the month of February. Similarly to supply temperature of 60°C, despite the average outdoor temperatures in that period is below zero at all times, the clear sky allows for daily peak of up to 6,5kW from each 10m² of solar panels.

![Graph showing collector field yield with temperature data](image-url)

Figure **No text of specified style in document**. Weather data and collector field yield during the month of February, location Mongolia, for 10m² collectors are at a slope of 60deg.
Based on above data the consultant calculated the monthly heat production capacity for each m² of collector.
Table Error! No text of specified style in document.-3 Monthly heat production with supply temperature of 80°C

<table>
<thead>
<tr>
<th></th>
<th>kWh/m²/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>39.1</td>
</tr>
<tr>
<td>February</td>
<td>54</td>
</tr>
<tr>
<td>March</td>
<td>71.6</td>
</tr>
<tr>
<td>April</td>
<td>54.2</td>
</tr>
<tr>
<td>May</td>
<td>49.1</td>
</tr>
<tr>
<td>June</td>
<td>37</td>
</tr>
<tr>
<td>July</td>
<td>44</td>
</tr>
<tr>
<td>August</td>
<td>48.9</td>
</tr>
<tr>
<td>September</td>
<td>54</td>
</tr>
<tr>
<td>October</td>
<td>65.4</td>
</tr>
<tr>
<td>November</td>
<td>43</td>
</tr>
<tr>
<td>December</td>
<td>31.7</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>592</strong></td>
</tr>
</tbody>
</table>

*Note: The highest heat production may be achieved in March with approx 71.6 kWh for each m². To be able to produce that amount of heat, the average heat production in March is in the magnitude of 0.096 kW per m².*

As observed at the Figure Error! No text of specified style in document.-6 presenting the yearly collector field yield, the maximum production is around 0.72kW/m² and consequently the required panel's area for 10MW Solar Thermal Panel Plant should be of around 13,890m². To be able to utilize the panel's capacity to the maximum the proper angle and distance between panels should be maintained. For panel's installation purposes, usually a land area three times larger than the panel area is assumed. In this case it would have to be an area of approx. 4.2 ha.

The expected yearly production of heat with 80°C supply temperature is in the magnitude of 7,070 Gcal.
The solar plant of 10MW capacity avoids the emission of at least 11,000 tons of CO\textsubscript{2} annually. Another advantage of the solar panel plant is the short implementation time that may be completed within few weeks. In order to be able to utilize the heat produced during the high demand hours the storage tank should be installed together with the panel’s installation. The calculated supply temperatures of 80°C may support the secondary district heating system of Ulaanbaatar. The supply temperatures of 60°C would require the isolated, low temperature system, possibly supported by e.g. electric power to heat boiler possibly utilizing power produced by windmills.

### 1.1.3 Photovoltaics

The consultant also made an estimation of the electrical power possible to be produced with Solar PV’s per m\textsuperscript{2} of the panel. Very good quality, monocrystalline solar PV panels with cell efficiency of 20% are assumed.
The amount of heat produced with 80°C output temperature is factor 4 more than electrical energy. The advantage of electrical energy is that the PV solar plant may be located out of Ulaanbaatar while the solar heat plant has to be located within the close range of the district heating network.

<table>
<thead>
<tr>
<th>PV panels</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>March production per 10 m²</td>
<td>295 kWh/10m²/March</td>
</tr>
<tr>
<td>Average production in March per 1 m²</td>
<td>29.5 kWh/m²/March</td>
</tr>
<tr>
<td>Maximum production per m²</td>
<td>0.20 kW/m²</td>
</tr>
<tr>
<td>10 MW production collector’s area required</td>
<td>49,505 m²</td>
</tr>
<tr>
<td>10 MW production collector’s area required</td>
<td>4.95 ha</td>
</tr>
<tr>
<td>Assessed land required</td>
<td>14.85 ha</td>
</tr>
<tr>
<td>Yearly output for 10MW PV panels</td>
<td>12,970 MWh/year</td>
</tr>
<tr>
<td>Yearly output for 10MW PV panels</td>
<td>11,154 Gcal/year</td>
</tr>
<tr>
<td>CAPEX</td>
<td>12,030,075 USD</td>
</tr>
<tr>
<td>OPEX</td>
<td>601,504 USD/year</td>
</tr>
</tbody>
</table>

To be able to achieve similar capacity at the PV’s as at the solar heating plant the CAPEX will have to be approx. factor 4 higher. These two types of installations should not be directly compared as the heat and electric power exergy are totally different.

1.2 Utilisation of biomass

No source of biomass possible to utilize in a sustainable manner has been identified, ref. Section Error! Reference source not found..
In the present section an estimate of the quantity of biomass required to replace the quantity of coal used at the heat sources in Ulaanbaatar is made.

**Heat Only Boilers**

The heat only boilers (Amgalan) could be replaced by wood chip fired heat only boilers. Wood chip is a fuel a very high moisture content (say 40%). Assuming that the wood chip fired boilers are constructed with the possibility to condense vapor (and that the temperature of the district heating return water is sufficiently low to make it possible to condense the vapor in the flue gas) the overall efficiency of a wood chip fired boiler cold be say 105%

*Table Error! No text of specified style in document.*-7 Theoretical evaluation of required quantity of wood chip to provide similar heat output as coal combusted at Amgalan heat only boiler plant.

<table>
<thead>
<tr>
<th>Present situation</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Coal</td>
</tr>
<tr>
<td>Calorific value</td>
<td>3,330 kcal/kg</td>
</tr>
<tr>
<td>Calorific value</td>
<td>13.9 GJ/ton</td>
</tr>
<tr>
<td>Humidity</td>
<td>35.0 %</td>
</tr>
<tr>
<td>Annual fuel consumption, 2018</td>
<td>225,385 ton/year</td>
</tr>
<tr>
<td>Energy content in fuel</td>
<td>3,141,727 GJ/year</td>
</tr>
<tr>
<td>Heat output, 2018</td>
<td>641 1,000 Gcal/year</td>
</tr>
<tr>
<td>Heat output, 2018</td>
<td>2,683,226 GJ/year</td>
</tr>
<tr>
<td>Efficiency</td>
<td>85 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alternative fuel</th>
<th>Wood chip</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>Wood chip</td>
</tr>
<tr>
<td>Calorific value</td>
<td>2,484 kcal/kg</td>
</tr>
<tr>
<td>Calorific value</td>
<td>10.4 GJ/ton</td>
</tr>
<tr>
<td>Humidity</td>
<td>40.0 %</td>
</tr>
<tr>
<td>Annual fuel consumption, 2018</td>
<td>245,717 ton/year</td>
</tr>
<tr>
<td>Energy content in fuel</td>
<td>2,555,453 GJ/year</td>
</tr>
<tr>
<td>Heat output, 2018</td>
<td>641 1,000 Gcal/year</td>
</tr>
<tr>
<td>Heat output, 2018</td>
<td>2,683,226 GJ/year</td>
</tr>
<tr>
<td>Efficiency</td>
<td>105 %</td>
</tr>
</tbody>
</table>

*Table Error! No text of specified style in document.*-7 shows that 246,000 ton per year of wood chip (40% humidity) will be required to provide a similar heat output as the heat only boilers at Amgalan provide by combustion of 225,000 ton coal per year.
Theoretical evaluation of required quantity of wood pellets to provide similar electric power and heat output as coal combusted at the coal fired co-generations plant in Ulaanbaatar. Note that it is assumed that the overall plant efficiency is identical for coal combustion and for a similar pant using wood pellets as fuel.

### Present situation

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorific value</td>
<td>3,600 kcal/kg</td>
</tr>
<tr>
<td>Calorific value</td>
<td>15.1 GJ/ton</td>
</tr>
<tr>
<td>Humidity</td>
<td>40.0 %</td>
</tr>
<tr>
<td>Annual fuel consumption, 2018</td>
<td>4,793,460 ton/year</td>
</tr>
<tr>
<td>Energy content in fuel</td>
<td>72,235,525 GJ/year</td>
</tr>
<tr>
<td>Useful energy output (electric power + heat)</td>
<td>9,204,1,000 Gcal/year</td>
</tr>
<tr>
<td>Useful energy output (electric power + heat)</td>
<td>38,527,944 GJ/year</td>
</tr>
<tr>
<td>Efficiency</td>
<td>53 %</td>
</tr>
</tbody>
</table>

### Alternative fuel

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Wood pellets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calorific value</td>
<td>4,181 kcal/kg</td>
</tr>
<tr>
<td>Calorific value</td>
<td>17.5 GJ/ton</td>
</tr>
<tr>
<td>Humidity</td>
<td>7.0 %</td>
</tr>
<tr>
<td>Annual fuel consumption, 2018</td>
<td>4,153,956 ton/year</td>
</tr>
<tr>
<td>Energy content in fuel</td>
<td>72,694,234 GJ/year</td>
</tr>
<tr>
<td>Useful energy output (electric power + heat)</td>
<td>9,204,1,000 Gcal/year</td>
</tr>
<tr>
<td>Heat output, 2018</td>
<td>38,527,944 GJ/year</td>
</tr>
<tr>
<td>Efficiency</td>
<td>53 %</td>
</tr>
</tbody>
</table>

Table shows that 4.2 million ton per year of wood pellets (7% humidity) will be required to provide a similar output of electric power and heat as the co-generation plants provide by combustion of 4.8 million ton coal per year. The assessment is made under the assumption that the overall plant efficiency for the wood chip based co-generation plants are identical to the efficiency of the present co-generation plants, i.e. 53%. Note, the comparison with wood chip is made as this fuel is the typical alternative to coal as e.g. as combustion of wood chip by pulverization is a proven technology (similar to coal dust fired boilers). Note that the biomass source (wood) has to be processed to form wood chips with low humidity, i.e. significantly higher tonnage of raw material (wood) is required to produce the stated quantity of fuel.