Solar chimney project in Arizona: an energy budget basic check

A paper, which has been published in October 2011, in the review "Sun & Wind energy", provides useful information about a solar chimney project in Arizona. The basic figures which are mentioned in this article can be checked in the following way.

As can be read at top of page 5[1], the delivered design power will be 200 MW. Page 3, the following sentence is quoted: "Our plant will get a 60 percent capacity factor, meaning it will operate at maximum power 60 percent of the time". Hence, the annual delivered energy should be: 200 x 60 % x 365 x 24 = 1,051,200 MWh/y = 1,051 GWh/y

This can be compared to the solar energy which is received by the relevant land area. In Jörg Schlaich's book, "The solar Chimney", page 11, a solar radiation world map calls "well suited regions" those whose solar input is between 1950 and 2200 kWh/m²y, and "very well suited" those above 2200 kWh/m²y. Hence, a top location could be around 2400 kWh/m²y. This has to be multiplied by the collector's area, which (bottom of page 1 of Enviromission's paper) is 5,500 acres, i.e. 22.26 km². So, the total received solar energy is: 2,400 kWh/m²y x 22.26 km² = 53,420 GWh/y.

It results from all this that, for a chimney's height which will be 762 m (top of page 5), the assumed global system's efficiency is: (1,051 GWh/y) / (53,420 GWh/y) = 0.0196 = 1.96 %.

Still in Jörg Schlaich's book, pages 36-37, a 750 m chimney is described (column "30 MW") with a 1 % whole system's efficiency, just half of Enviromission's claim with a quite equal chimney's height.

This efficiency arises from the chimney's theoretical efficiency, reduced by various losses.

The theoretical efficiency is very well known, it writes: $\eta = \lambda h_t / T_o$, where λ is the air's dry adiabatic gradient[2], i.e. around 10 K/km, and T_o is the incoming air absolute temperature, i.e. around 300 K, so that the η efficiency is around 3.33 % for each chimney kilometre. This is why, in Jörg Schlaich's book, page 37, you get a 3.10 % efficiency for a 950 m chimney, and 2.33 % for a 750 m one.

Here, for a 762 m one, we can take: η = (10/3) * 762 % = 2.54 %.

This means that with his 1.96 % overall efficiency claim, Enviromission assumes that all the other losses account for only (2.54 - 1.96) / 2.54 = 23 % of the theoretical output. This should be compared to Schlaich's losses for the 750 m chimney: (2.33 - 1) / 2.33 = 57 %.

Hence, Enviromission seems to be relying on very optimistic losses, as these 23 % should account for:
- reflection losses at the top and at the bottom of each air / ETFE plastic[3] dioptre;

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[1] Due to adverts, useful pages are 1, 3, 5 and 6, but I keep these numbers.

[2] $$\lambda = \frac{gM}{(7/2)R} = \frac{9.81\,\mathrm{m/s^2} * 0.029\,\mathrm{kg/mol}}{8.32\,\mathrm{J/mol.K} * (7/2)} \approx 10\ \mathrm{°/km}$$

[3] With a possibly smaller refraction index than glass, this can explain a small part of the reduced losses with comparison with Schlaich's project. But these losses may not be negligible, as we can read in http://www.agcce.com/brochurespdfs/sales/corporatenew.pdf about the products of a society which is producing

- absorption losses by the ground (as it is possibly not perfectly black);
- thermal infrared reemissions (even if ETFE may have been chosen for its greenhouse effect, i.e. its ability to stop these reemissions and be heated by them);
- heat conduction through this canopy (air temperature in the collector may rise up to 80 or 90 °C, Cf. page 3, and the canopy itself is being heated, Cf. supra);
- turbulent air friction inside the collector and the chimney;
- kinetic energy losses at the chimney exit (if[4] the air velocity is the same as by the turbines, i.e. 56 km/h or 15 m/s, the “pressure drop at chimney top”, commonly assessed as $\frac{1}{2} \rho v^2$, would be higher than 100 Pa, hence notably higher than 10 % of the theoretical output);
- turbines and alternator mechanical and magneto-electrical losses.

Reaching 2.5-times lower losses[5] than in Jörg Schlaich’s book seems a strong claim, and maybe not an economical optimum if all relevant components must be so perfect that they can be called a Rolls Royce car.

Another cause for such optimistic figures may arise from the use of a global efficiency formula which would have been extrapolated outside its domain of best relevance. Maybe one year ago, I had noticed such a case in a brochure by Wilfried B. Krätzig, and he admitted such a mistake and the fact that it illustrated the “dangers of wishful thinking”.

Anyway, more details of the Arizona project should be investigated, and maybe a scientific paper in a peer-reviewed journal would be a good thing in order to wipe all doubts away.

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ETFE, that 1.34 is a low value for refractive indices: “*Cytop is an amorphous fluoropolymer / Cytop has good solubility in certain fluorinated solvents due to its amorphous nature. Cytop also maintains a low refractive index of 1.34*”. See also http://www.norton-films.com/uploadedFiles/SGNortonFilms-NA/Documents/HP/HPFilms-ETFE-AFF1006R.pdf : “For “Norton ETFE films : … Refractive Index : 1.40”. For a 1.4 index, for each dioptre (at least two of them), the reflection factor is around $(0.4/2.4)^2$, i.e. 2.7 %, hence 5.4 % for a whole film reflection losses.

[4] This can’t be checked precisely as the chimney’s diameter is unknown, but the 15 m/s order of magnitude is quite common. We can also see on the drawings that no diffuser is designed in order to reduce these losses.

[5] 23 % compared to 57 %.