Feasibility studies for various examples of AirHES

Baseline:

1. Getting water from fog (minimum estimation)

   - According to Chilean plants : 3-13 L/m2/day
   - According to FogQuest : 5-25 L/m2/day
   - According to LWC for fog (0.05 g/m3) at wind speeds near the ground in the mountains ~5 m/s and mesh efficiency ~50% : 10.8 L/m2/day (by calculation)

   We can see that the calculated data agree well with the experimental data for passive fog collectors. Thus, if we take these data as a basis for estimates of minimum water collecting in the clouds, we can take 10 L/m2/day as a lower limit in the feasibility study.

2. Getting water from the clouds (average estimation)

   - According to active (omni-directional) highland fog collectors (really similar to clouds) : 160-300 L/m2/day
   - According to LWC for stratus and cumulus clouds (0.25-0.45 g/m3) at wind speeds at a height of clouds ~10 m/s and mesh efficiency ~50% : 108.0-194.4 L/m2/day (by calculation)

   We can see that the calculated data agree well with the experimental data for active (omni-directional) fog collectors, which are similar to AirHES. Thus, if we take these data as a basis for estimates of average water collecting in the clouds, we can take 100 L/m2/day as a base value in the feasibility study.

3. Getting water from the clouds (maximum estimation)

   - According to LWC and scientific observations for cumulonimbus and thunderclouds (1-3 g/m3) at wind speeds at a height of clouds ~15 m/s and mesh efficiency ~50% : 648-1944 L/m2/day (by calculation)

   Thus, if we take these data as a basis for estimates of maximum water collecting in areas of high rainfall (in the equatorial zone, as well as in southern India and China), we can take 1000 L/m2/day as the upper limit in the feasibility study.

Scientific prototype

This is a minimal device used for obtaining experimental data to collect water from the clouds and for verification of design solutions. Like fog collector study we can use the SFC (standard fog collector, 1 m2). Such device has been tested on Seliger 13/07/30 with the rise to a height of ~1.5 km, but during descent the rope was broken and device was destroyed. Tests have shown that an alternative design based on the kite may have the advantage due to the use of aerodynamic lift forces, but the design is a need for more detailed and complex aerodynamic calculations (XFlow, ANSYS, etc.). Hydraulic calculation is performed to find the minimum hose diameter that allows this stream to flow in waterfall mode (i.e., such a diameter that corresponds to equal flow resistance and small hydraulic head on a part of hose, for example, a length of 10 m = 1 atm). Calculation in the table is given for a height of 2 km. To estimate the aerodynamic lift of the kite used simplified formula $0.04*V^2*S$ at wind speeds of 5 and 10 m/s. To assess the aerostatic lift of the balloon is assumed that every m3 of hydrogen or helium corresponds approximately 1 kg weight.

		On the basis of balloon			On the basis of kite (5-10 m/s)		
Water collection rates, L/m2/day	Tested prototype	10	100	1000	10	100	1000
Collection area, m2	0.9	1	1	1	1	1	1
Flow, m3/h	[~0.005]	0.000417	0.00417	0.0417	0.000417	0.00417	0.0417
Minimum Diameter, mm	[1.55] 2.0x0.4	0.84	1.48	2.23	0.84	1.48	2.23
Water weight in hose, kg	[3.77]	1.11	3.44	7.81	1.11	3.44	7.81
PVC hose weight (wall thickness 0.5 mm), kg	[6.82] 7.04 ($60)	3.70	6.50	9.81	3.70	6.50	9.81
Rope weight (dyneema 1.2 mm), kg	2.2 ($256)	2.2	2.2	2.2	2.2	2.2	2.2
Weight of double layer of mesh with drops, kg	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Weight of auxiliary elements, kg	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Load weight, kg	[14.0]	8.21	13.34	21.02	8.21	13.34	21.02
Calculated radius of balloon (selection), m	1.52	1.53	1.75	1.97			
Balloon shell weight (PVC 0.16 mm), kg	6.5 ($550)	4.75	8.6	10.9			
Balloon volume, m3	14.7	15.0	22.4	32.0			
Kite area, m2					8.2-2.05	13.4-3.35	21.0-5.25
Kite weight (45 g/m2), kg					0.37-0.09	0.60-0.15	0.95-0.24

Minimum technical prototype

It's a full technical plant, which will allow at minimum cost to check the design elements and feasibility study of the concept AirHES. It differs from the scientific prototype that it contains the penstock (pressure hose), the hydraulic turbine (or hydraulic motor) and generator. When calculating the thickness of the wall of the hose (reinforced by dyneema with an estimated strength of 2.4 GPa) used a 5-fold margin of safety. The hose plays also the role of a rope, which can be verified in the most intense upper point where the calculated margin of safety is equal to 9.25 in all variants. Expected lifetime of plant - 10 years.

	On the basis of balloon			On the basis of kite (5-10 m/s)		
Water collection rates, L/m2/day	10	100	1000	10	100	1000
Collection area, m2	100	100	100	100	100	100

Flow, m3/h	0.0417	0.417	4.17	0.0417	0.417	4.17
Diameter with 10% head loss, mm	5.45	8.4	20.0	5.45	8.4	20.0
Water weight in hose, kg	46.7	110.8	628.3	46.7	110.8	628.3
The calculated wall thickness at 20 MPa at 5-fold margin of safety, mm	0.11	0.18	0.42	0.11	0.18	0.42
Hose weight (dyneema), kg	3.77	8.95	50.76	3.77	8.95	50.76
Weight of double layer of mesh with drops, kg	20.0	20.0	20.0	20.0	20.0	20.0
Load weight, kg	70.4	139.7	698.8	70.4	139.7	698.8
The calculated radius of balloon (selection by aerostatic balance), m	2.73	3.39	5.67			
Balloon shell weight (155 g/m2), kg	14.51	22.4	62.6			
Balloon volume, m3	85.2	163.1	763.2			
Kite area, m2				70-17.5	140-35	700-175
Kite weight (45 g/m2), kg				3.15-0.79	6.3-1.58	31.4-7.9
Power with efficiency 80%, kW	0.185	1.85	18.5	0.185	1.85	18.5
Cost of mesh ($0.25/m2)*2, $	50	50	50	50	50	50
Cost of hose ($100/kg), $	377	895	5076	377	895	5076
Cost of shell ($3/m2), $	281	433	1212			
Cost of kite ($2/m2), $				140	280	1400
Sum Cost of material, $	708	1378	6338	567	1225	6526
Cost + Work (by doubling), $	1416	2756	12676	1134	2450	13052
Cost of turbine+generator (by doubling a similar kW motor), $	~70	~150	~1000	~70	~150	~1000
Total Cost, $	1486	2906	13676	1204	2600	14052
Specific Cost, $/kW	8032	1571	739	6508	1405	760
Water (income for 10 yrs, $1/м3), $K	3.65	36.5	365	3.65	36.5	365
Electricity (for 10 yrs, $0.1/kWh), $K	1.62	16.2	162	1.62	16.2	162
Total income for 10 yrs, $K	5.27	52.7	527	5.27	52.7	527
ROI for 10 yrs, %	355	1813	3858	438	2027	3756
Payback period, yrs	2.82	0.55	0.26	2.28	0.49	0.27
ROI (only Electricity) for 10 yrs, %	109	557	1187	134	623	1156
Payback period (only Electricity), yrs	9.17	1.79	0.84	7.43	1.60	0.87
Water & Electricity supply, persons	~1	~10	~100	~1	~10	~100

Basic technical prototype

It's a full technical plant, which will allow for the water and electricity of small villages and towns by using AirHES. It contains a penstock (pressure hose), the hydraulic turbine (or hydraulic motor) and the electric generator. When calculating the thickness of the wall of the hose (reinforced by dyneema with an estimated strength of 2.4 GPa) used a 5-fold margin of safety. The hose plays also the role of a rope, which can be verified in the most intense upper point where the calculated margin of safety is equal to 9.25 in all variants. Expected lifetime of plant - 10 years.

	On the basis of balloon			On the basis of kite (5-10 m/s)		
Water collection rates, L/m2/day	10	100	1000	10	100	1000
Collection area, m2	10000	10000	10000	10000	10000	10000
Flow, m3/h	4.17	41.7	417	4.17	41.7	417
Diameter with 10% head loss, mm	20.0	47.7	140	20.0	47.7	140
Water weight in hose, kg	628	3572	30772	628	3572	30772
The calculated wall thickness at 20 MPa at 5-fold margin of safety, mm	0.42	0.99	2.92	0.42	0.99	2.92
Hose weight (dyneema), kg	50.76	288.8	2487	50.76	288.8	2487
Weight of double layer of mesh with drops, kg	2000	2000	2000	2000	2000	2000
Load weight, kg	2678	5861	35259	2678	5861	35259
The calculated radius of balloon (selection by aerostatic balance), m	8.78	11.35	20.51			
Balloon shell weight (155 g/m2), kg	150	251	819			
Balloon volume, m3	2833	6121	36121			
Kite area, m2				2678-670	5861-1465	35259-8814
Kite weight (45 g/m2), kg				120-30	264-66	1587-396
Power with efficiency 80%, kW	18.5	185	1853	18.5	185	1853
Cost of mesh ($0.25/m2)*2, $	5000	5000	5000	5000	5000	5000
Cost of hose ($100/kg), $	5076	28875	248740	5076	28875	248740
Cost of shell ($3/m2), $	2905	4854	15850			
Cost of kite ($2/m2), $				5358	11722	70518
Sum Cost of material, $	12981	38729	269591	15434	45597	324259
Cost + Work (by doubling), $	25962	77459	539181	30868	92194	648518
Cost of turbine+generator (by doubling a similar kW motor), $	~1000	~8000	~50000	~1000	~8000	~50000
Total Cost, $	26962	85459	589181	31868	99194	698518
Specific Cost, $/kW	1457	461	317	1719	535	377
Water (income for 10 yrs, $1/м3), $K	365	3652	36529	365	3652	36529
Electricity (for 10 yrs, $0.1/kWh), $K	162	1624	16235	162	1624	16235
Total income for 10 yrs, $K	528	5276	52764	528	5276	52764
ROI for 10 yrs, %	1958	6174	8956	1656	5319	7554

Payback period, yrs	0.51	0.16	0.11	0.60	0.19	0.13
ROI (only Electricity) for 10 yrs, %	601	1900	2756	509	1637	2756
Payback period (only Electricity), yrs	1.66	0.53	0.36	1.96	0.61	0.43
Water & Electricity supply, persons	~100	~1000	~10000	~100	~1000	~10000

Further increase of power

In principle, the same pattern can be calculated and for the next generation - high power module with a network of ~1 km2. However, we already reach the limit values for the size of balloons and kites. To go to this power, we should change the design solutions. For example, we can use the meshes themselves as kites to support the basic weight of the produced water in the hose, and to use the balloon only to support meshes and empty hose in complete calm. This will demand the creation of an appropriate control system (preferably by using a natural physical feedback), which will monitor wind speed and emergency dumping or spraying water from the hose under the threat of falling. Here is an example calculation of the feasibility study of such plant.

Water collection rates, L/m2/day	10	100	1000
Collection area, km2	1	1	1
Flow, m3/h	417	4170	41700
Diameter with 10% head loss, mm	140	385	900
Water weight in hose, kg	30772	232713	1271700
Calculated wall thickness at 20 MPa at 5-fold margin, mm	2.92	8.02	18.75
Hose weight (dyneema), kg	2487	18811	102796
Weight of double layer of mesh with drops, kg	200000	200000	200000
Load weight (without water weight in hose), kg	202487	218811	302796
Calculated radius of balloon (selection by aerostatic balance), m	36.59	37.55	41.82
Balloon shell weight (155 g/m2), kg	2606	2745	3404
Balloon volume, m3	205095	221666	306211
Power with efficiency 80%, kW	1853	18533	185333
Cost of mesh ($0.25/m2)*2, $	500000	500000	500000
Cost of hose ($100/kg), $	248740	1881099	10279575
Cost of shell ($3/m2), $	50447	53129	65899
Sum Cost of material, $	799187	2434228	10845474
Cost + Work (by doubling), $	1598375	4868455	21690948
Cost of turbine+generator (by doubling a similar kW motor), $	~50000	~300000	~1000000
Total Cost, $	1648375	5168455	22690948
Specific Cost, $/kW	889	279	122
Water (income for 10 yrs, $1/м3), $K	36529	365292	3652920
Electricity (for 10 yrs, $0.1/kWh), $K	16235	162352	1623520
Total income for 10 yrs, $K	52764	527644	5276440

ROI for 10 yrs, %	3201	10208	23253
Payback period, yrs	0.31	0.10	0.04
ROI (only Electricity) for 10 yrs, %	984	3141	7155
Payback period (only Electricity), yrs	1.02	0.32	0.14
Water & Electricity supply, persons	~10000	~100000	~1000000

This also should include the need to develop a system of the automatic and interconnected accumulation of the water storage upstream and the hydrogen in ballonet balloons that will significantly reduce meteo-dependence of AirHES without using external storage (which dramatically increase the cost of wind and solar plants).

Finally, for GW plants it can be quite cost-effective construction of vertical pressure tube (or even waterfall tube) height of 1-2 km with feeding from located around the meshes with total size of tens of square kilometers.

Irrigation project

This is a special plant that can produce rain in arid areas for creating an oasis in the desert or rain over anhydrous island (like Malta, for example). It has no hose, but may have elements of the drainage system for generating a jet of water to reduce evaporation of rain on the way to the ground. It may be made both through the balloon (possibly by using icing effect on high altitude), and on the basis of the kite (then possible to use only at positive temperatures, which restricts the height and, accordingly, the area coverage of such plant).

Let's estimate, for example, the area of mesh of irrigation AirHES to create an oasis in some place in the Sahara desert. For example, take the meteorological data for the year to Egypt - Wadi El Rayan. It is seen that there is practically no rain, but the clouds for the year can be estimated at 10%. On ARL sounding diagram, we can estimate the height of the clouds about 4 km. With a typical deviation from the vertical ~15 degrees we obtain the irrigation area about 3 km2. If we want to create a comfortable area there with average level of precipitation on the planet ~1 m per year, this gives a flow ~8200 m3/day, which for the average estimation by getting the water out of the clouds gives the mesh area 82000 m2, and taking into account 10% of meteorological evaluation of cloudiness increases this size an order of magnitude to 0.82 km2.

Project for drinking water supply

This is probably the most profitable startup project for all variants of AirHES. This plant is similar to the irrigation project, but differs in that has hose with a gravity flow (like a scientific prototype). Since such hose in essence is just a channel of waterfall, it should not withstand the pressure of the water column at 2 km. Balloon must keep its own weight, the weight of hose with flowing water, and the weight of the meshes with residual water. With calculating the hose from dyneema with 5-fold margin of safety at the top of hose it is necessary to consider only its own weight and the weight of flowing water in it.

Consider, for example, water supply of Malta (452 thousand people), the only state which does not have its own fresh water. Meteorological data show that excepting the two summer months in the rest of the time over Malta there is normal distribution of the clouds, however Malta has no high mountains and therefore has no natural sources of fresh water.

Water collection rates, L/m2/day	10	100	1000
Collection area, km2	1	1	1
Flow, m3/h	417	4170	41700
Minimum Diameter, mm	102	240	570
Water weight in hose, kg	16334	90432	510093
Calculated wall thickness for strength at the top, with 5-fold margin of safety, mm	1.11	2.61	6.19
Hose weight (dyneema), kg	690	3816	21493
Weight of double layer of mesh with drops, kg	200000	200000	200000
Load weight (with water weight in hose), kg	217024	294247	731586
Calculated radius of balloon (selection by aerostatic balance), m	37.45	41.43	56.07
Balloon shell weight (155 g/m2), kg	2730	3342	6120
Balloon volume, m3	219899	297724	738006
Cost of mesh ($0.25/m2)*2, $	500000	500000	500000
Cost of hose ($100/kg), $	68969	381678	2149299
Cost of shell ($3/m2), $	52846	64676	118460
Sum Cost of material, $	621815	946253	2767759
Cost + Work (by doubling), $	1243630	1892507	5535518
Water (income for 10 yrs, $1/м3), $K	36529	365292	3652920
ROI for 10 yrs, %	2937	19302	65991
Payback period, yrs	0.34	0.05	0.02
Water supply, persons	~10000	~100000	~1000000