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HOW TO ADVANCE GEOTHERMAL HEAT PUMPS? THE EXAMPLES OF SWITZERLAND AND THE HYY SINGLE WELL SYSTEM IN CHINA

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ABSTRACT

Several supportive factors need to interplay at the same time to enable large-scale dissemination of GHP technology. For Switzerland, technical, political and economic influence factors enabled the rapid growth in installed capacity. The density of energy supply from GHP systems (MWh/yr per km^2) secures Switzerland a prominent international rank in geothermal direct use.

In China the innovative approach of the HYY Single Well System now widely used –also for facilities of the 2008 Beijing Olympics– demonstrates the potential of GHPs for various building types and use options.

The main success factor is information/outreach to disseminate knowledge and know-how about the design, operation and benefits of GHP systems.

1. INTRODUCTION

Geothermal heat pumps (GHP) represent nowadays the fastest growing branch in the utilization of geothermal energy (Rybach, 1998; 2004; 2005). Its advance or retardation still varies, to quite some extent, from country to country. There are various influence factors that can lead to the successful dissemination of the GHP technology. Several of these have been in play, both in Switzerland and partly also in China.

The promoting factors are manifold: technical, economic, environmental awareness, governmental support, etc. The most important driving force is simply knowledge and know-how. Besides, various applications and wide-scale realizations, high-level quality assurance and successful demonstration facilities are needed.

This contribution first summarizes the achievements in Switzerland and the promoting influence factors; then the deployment of a specific, innovative solution and its applications are described for China.

2. THE ACHIEVEMENTS OF SWITZERLAND

2.1 World Rank

GPHs are the main contributors to geothermal direct use in Switzerland: they provided 92% of the heat production in 2006 (Signorelli et al. 2008). Thanks to the widespread use of GHPs Switzerland occupies a prominent international rank in direct use, when in ranking, not only the absolute numbers are considered but also the country size. In terms of areal density of production (produced GWh per year and country surface) Switzerland ranks second after Iceland, see Table 1.

TABLE 1: The world-wide top 15 in geothermal direct use, and ranking in terms of areal density of production capacity. Ranking calculated from data in Fridleifsson et al. (2008).

Country	**GWh/yr**	**Country area 10^3 km^2**	**GWh/yr per 10^3 km^2**	**Rank**
China	12,605	9571	1.32	12
Sweden	10,000	450	22.2	6
USA	8,678	9809	0.88	13
Turkey	6,900	779	8.86	7
Iceland	6,806	103	66.1	1
Japan	2,862	378	7.57	8
Hungary	2,206	93	23.7	5
Italy	2,098	301	6.97	10
New Zealand	1,968	271	7.26	9
Brazil	1,840	8512	0.22	14
Georgia	1,752	70	25.0	4
Russia	1,707	17075	0.10	15
France	1,443	544	2.65	11
Denmark	1,222	43	28.4	3
Switzerland	1,175	41	28.7	2

2.2 Growth Rate, Learning Curve

The advance of GHPs in Switzerland is impressive, especially for systems with borehole heat exchangers (BHE). Presently more than one GHP system per km^2 operates in Switzerland. Figure 1 displays the installation development in the years 1990 – 2006 for BHE-coupled and groundwater-based heat pump systems. The greater popularity of BHE-coupled systems is mainly due to the fact that these can also be used for space cooling.

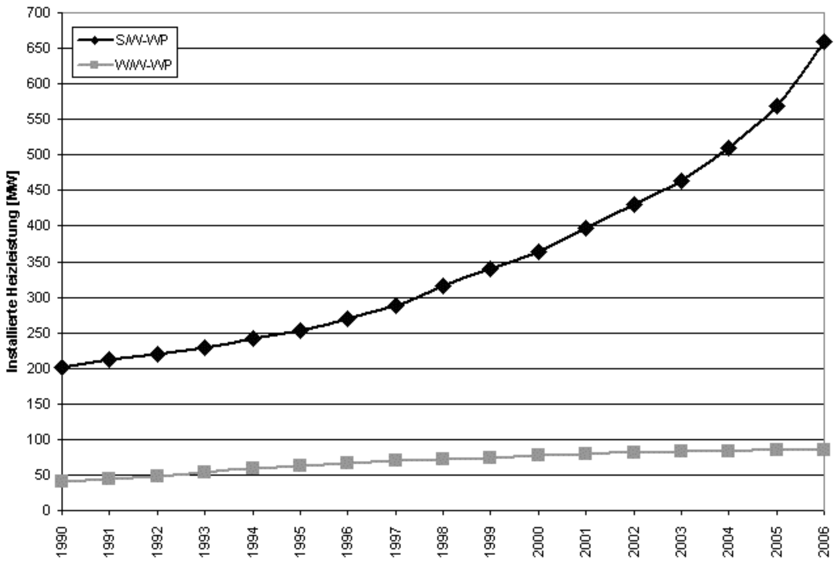

FIGURE 1: Increase of installed heating capacity (MW_{th}) from 1990 to 2006. The line S/W-WP is for BHE systems, W/W-WP for groundwater heat pumps. From Signorelli et al. (2008).

Due to the increasing demand for BHE-coupled systems the drilling activity in Switzerland is corresponding (Figure 2): in 2007 the total drilling meters for BHEs was nearly 1,500 km (!); currently more than 30 drilling companies offer their services.

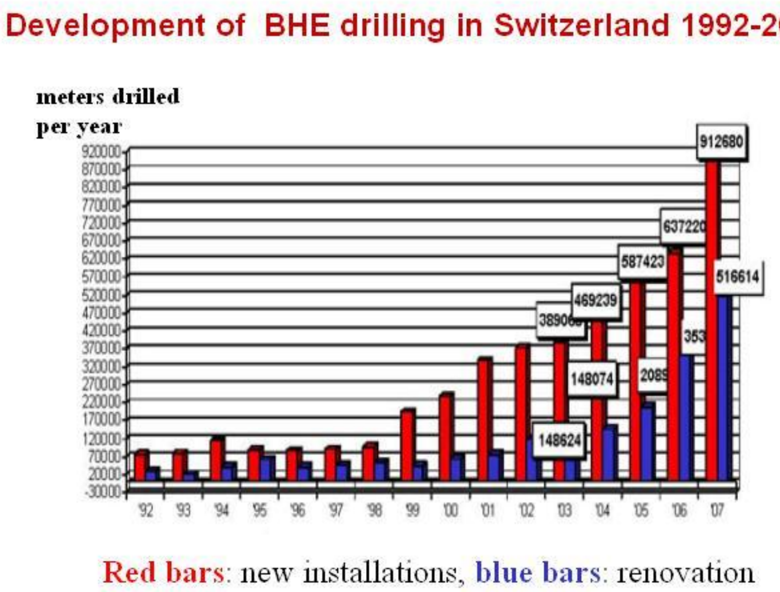

FIGURE 2: Increase of drilling activities for borehole heat exchanger-coupled geothermal heat pumps in Switzerland (From FWS, 2008).

Technology development, increasing experience and market competition led to significant installation cost reductions. Figure 3 shows a 110% decrease over the last 24 years. This can be considered as a "learning curve effect".

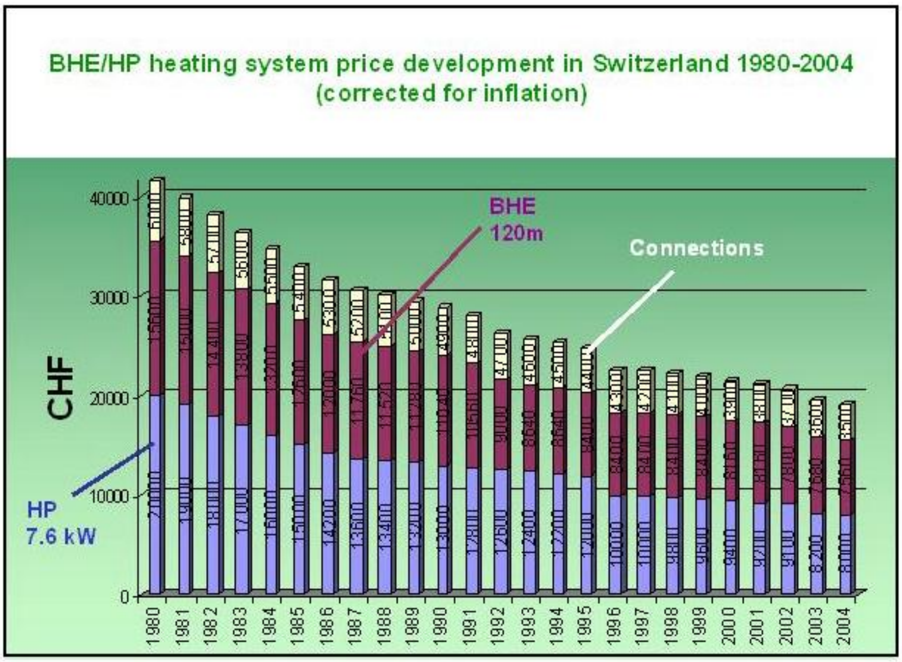

FIGURE 3: Installation costs of BHE-coupled geothermal heat pumps decrease significantly over time in Switzerland. 1 CHF ≈ 1 US $ (March 2008) (From Rybach and Minder, 2007).

3. POSITIVE INFLUENCE FACTORS IN SWITZERLAND

The impressive advance of GHP systems, as demonstrated above, is based on several supportive influence factors:

- Systems still in reliable operation after decades;
- Solid scientific background (theoretical and experimental studies of long-term operation, petrophysical data base, clarification of environmental and sustainability issues); there is a large volume of Swiss publications and reports on all these subjects;
- Supportive political and economic environment like subsidies and special electricity tariffs for heat pumps;
- Information/outreach to disseminate knowledge and know-how about GHP systems;
- Reliable system planning and design, now supported by an engineering norm;
- Technically sound and careful selection and installation of GHP equipment, now ascertained by quality labels;
- Considerate licensing/permitting by authorities, with focus on environmental protection e.g. of groundwater, now laid out in a Guideline.

The achievements are clearly visible in the geothermal direct use statistics of Switzerland: by far the largest contribution is provided by GHP installations. They are now routinely installed for space heating, cooling and domestic hot water production. In the following these influence factors are addressed and described in more detail.

3.1 Reliable long-term operation of GHP systems

There are several GHP installations in Switzerland that operate without any problems for many years (Rybach and Eugster, 2002). One example is the single family house of Mr. K.F. Stärk in Untersiggenthal/AG (heating capacity 11 kW, cooling capacity 5 kW). The system has operated to full satisfaction since 1986, even during the especially hot summer in 2003. The operational parameters are fully recorded and reported over the years (Stärk, 2004).

3.2 Solid scientific background

Scientific investigations of GHP systems started in the early 1980's. There is a large number of publications and reports about all facets of GHP systems: design, operation, environment, economics, etc. Most of it is in German; key publications in English can be found in the literature databases of the International Geothermal Association (IGA) and the Geothermal Resources Council (GRC). Special attention was given to key influence parameters like ground thermal conductivity or to system design (Rybach and Kohl, 2003).

3.3 Supportive promotion environment

The successful development of GHP systems in Switzerland profited –and still benefits– from various supportive influences:

- The Swiss Government provided, in the sense of an initiation, for several years subsidies (now finished) for newly installed heat pump systems
- Several Cantons still provide various subsidies (details see under http://www.fws.ch/zahlen_05.html)
- Local electric utilities provide subsidies and/or reduced tariffs for heat pumps; the electricity companies of Zurich city (EWZ;
- http://www.stadtzuerich.ch/internet/ewz/home/produkte/020506/
- Spezialtarife/waermepumpen-tarif.html
- and of Canton Zurich (EKZ; http://www.ekz.ch/internet/ekz/de/privatkunden/tarife.html) are prominent examples.

3.4 Information, outreach

A key promoter is the dissemination of technically correct but comprehensible information. Several, highly qualified organizations are active in this respect:

- Arbeitsgemeinschaft Wärmepumpen Schweiz, AWP
  Numerous info sheets („Technische Merkblätter") can be downloaded from www.awpschweiz.ch/de/liste-der-publikationen
- Förderverein Wärmepumpen Schweiz, FWS
  Various information ("Informations-Broschüren") can be downloaded from www.fws.ch/downloads
- Schweizerische Vereinigung für Geothermie, SVG
  Numerous info sheets ("technische Notizen") can be downloaded from www.geothermie.ch/index.php?p=documentation .

3.5 Reliable system planning and design (SIA Norm 384/6)

This is now guaranteed by a well-conceived Engineering Norm. In Switzerland, the Swiss Association of Architects and Engineers SIA, a high-level professional organization (http://www.sia.ch/) prepares and issues norms, also about construction, buildings, heating and cooling etc. Recently Norm SIA 384/6 "Erdwärmesonden" (="Borehole Heat Exchangers") was prepared.

Norm SIA 384/6 ascertains the proper planning, design, realization and operation of BHE-based GHP systems that utilize the heat source/ storage capabilities of the ground for heating and cooling of buildings. The goal is to lay down the technical requirements and quality criteria for such systems to ascertain the well-functioning of the installation, beyond the planned system lifetime.

3.5 Technically sound selection and installation of GHP equipment

3.5.1 Quality assurance for heat pumps

Heat pumps (HP) are a key component of a GHP system. The Swiss Heat Pump Promotion Association FWS (http://www.fws.ch) has been instrumental in the establishment of the Austrian-German-Swiss quality certificate system and label for heat pumps. The document "Internationales Wärmepumpen-Gütesiegel D-A-CH" comprises the rules of procedure and related requirements to obtain the quality certificate. The international quality certificate applies to air/water, brine/water, water/water and direct evaporation HP types. The document can be downloaded from http://www.fws.ch/fws_061.html. The HP quality system and label are now widely used in Switzerland; there is a special HP Test Center (at the University of Applied Sciences of Eastern Switzerland in Buchs/SG) where HPs are tested under standard conditions.

3.5.2 Quality assurance for BHE drilling and completion

The faultless conduct and accomplishment of BHE drilling is an equally important prerequisite of a reliably functioning GHP system. Again the Swiss FWS has established the quality certificate and label system for BHE drilling companies. This system functions since 2001; currently 22 Swiss drilling companies possess the quality label; it is expected that additional companies will obtain the label in the near future. The website http://www.fws.ch/zahlen_03.html displays the updated list of qualified drilling companies.

3.6 Licensing/permitting by authorities

Clear energy and environmental policies and regulations are of paramount importance for the development of renewable energy sources. The institutional framework, legislation and legal constraints are borderlines to delimit development, especially in view of environmental protection. Within these limits there should be unequivocal administration of law. Although the relevant legislation can vary significantly from country to country there are similarities: in most countries the guiding principles are based on groundwater protection.

In Switzerland there are various kinds of regulations, permits, and procedures for GHP systems, depending on the Canton of the GHP site(s). A recent Draft Guideline "Vollzugshilfe – Wärmenutzung aus Boden und Untergrund" of the Swiss Federal Office for the Environment (SFOEN) describes the regulatory domains and legal bases; it shall be published in the second half of 2008.

4. INNOVATIVE DEVELOPMENTS IN CHINA

Here the impact of innovative technology development is described, by the example of the HYY Single Well System, a GHP variant. The Beijing-based company "Beijing Ever Source Science & Technology Development Co., Ltd." (HYY) has developed the new, powerful groundwater heat pump system ("HYY Single Well System (SWS) of Supplying and Returning Water"), originally for the Beijing area, China. The new technology developed by HYY uses groundwater to provide heating for buildings in winter and to dispose heat in summer; the powerful system operates with a single well of about 50 – 100 m depth at 600 kW_{th} capacity. Domestic hot water is also supplied. The system works in a sustainable manner with a high efficiency and provides cooling without evaporation. In the following, the principle of system functioning is summarized and a comparison with other usage types is given. The hydrogeological prerequisites and the environmental and economic benefits are compiled in Xu and Rybach (2004), along with monitoring results to prove that operating systems have no effect on groundwater properties.

4.1 The HYY Single Well System

The HYY SWS uses "state-of-the-art surface" equipment, which consists of customary components like pumps, valves, heat exchangers, storage tanks, heat pumps, and control instrumentation. The innovative, basic, powerful unit of the SWS is its subsurface component, the "Single Well". Unlike traditional groundwater heat pump systems, where usually two wells are used (one for pumping the groundwater out and the other to dispose the cooled water) the HYY SWS applies production and reinjection to the same, specially designed water well.

For the HYY Single Well a borehole of about 70-80 m depth and with a diameter of 0.5 m is drilled. The necessary local geological site condition is to have a shallow aquifer with hydraulic conductivity of 10^{-3} m/sec or higher. Groundwater with a temperature of about 10 – 15°C is pumped from the well (lower, water production space) at a flow rate of about 50-100 m^3/h and passes through a wellhead heat exchanger (see Figure 3) where the return water from the heat pump picks up the groundwater's heat. The heat pump provides water with temperature of about 50 - 55°C to supply fan coilers for space heating whereas the temperature of the water released to the same well is lowered down to about 5 – 10°C. The water then goes to the upper, return space of the well by a return pipe. Due to the blocking functions of clapboards 1 and 2 this water cannot enter directly the lower part of the well (low pressure section) but goes out of the well through the meshes in the slotted well wall (patent holder: HYY) and takes heat from the surrounding sand and gravel. By these means, the water temperature returns back to its original temperature of 10 – 15°C in the ground in the vicinity of the well. This water with a recovered temperature of 10 – 15 °C flows again into the production (low pressure) space of the well. The maximum thermal power of a single well is around 0.6 MW_{th}. In summertime, "direct cooling" (i.e. with heat pump switched off) is provided by the groundwater after heat exchange.

4.2 Efficiency comparison with other geothermal usage types

The HYY Single Well System (SWS) provides, regardless its size, a very substantial geothermal supply capacity (several hundreds of kW). A comparison with other, similar usage types (conventional groundwater heat pumps, borehole heat exchangers, standing column wells, boreholes into deep aquifers) proves the great efficiency of the HYY SWS. For the comparison the specific thermal power capacity (Watt per meter borehole length) is calculated. The results are given in Table 2. The superiority of the HYY SWS is clearly demonstrated by the far highest W/m number in column 4. Besides the high specific capacity of this system the relatively small drilling depth needed is a further important advantage; drilling deeper like for other systems (except for the conventional groundwater heat hump system) is more costly and risky.

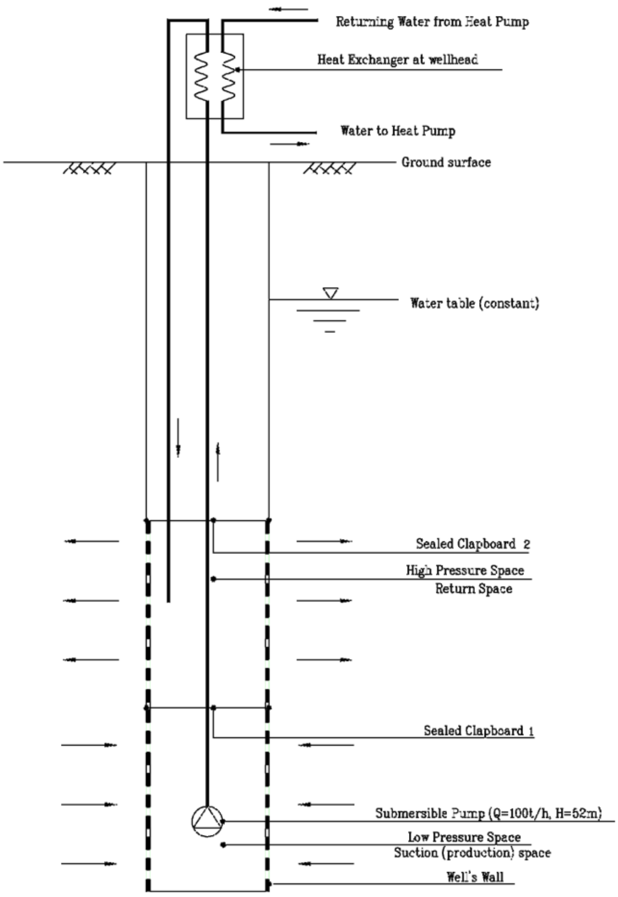

FIGURE 3: HYY Single Well System (SWS) for production from and reinjection into an aquifer. The lower part of the well, below clapboard 2, surrounded by a slotted wall, consists of an upper, pressurized reinjection section between clapboards 1 and 2 and a lower, low-pressure, water production section under clapboard 1 (From Xu and Rybach, 2005).

TABLE 2: HYY Single Well System (SWS) capacity comparison with other geothermal systems. From Xu and Rybach (2006).

System	**Well depth (m)**	**Total capacity (kW)**	**Specific capacity (W/m)**
Typical HYY system (SWS)	80	600	7500
Deep well to aquifer	2000	3600	1800
Typical conventional groundwater heat pump	50	50	1000
Standing column well (USA average)	377	200.6	532
Borehole heat exchanger – coupled heat pump (average borehole)	100	5	50

4.3 Examples of application, operational experience

The HYY SWS can be applied to a wide variety and scale of buildings. Successful applications, from various parts of China, encompass a correspondingly wide range of building types and purposes: residential buildings (single family houses and apartments), office buildings, hotels, hospitals, factories, shopping centres, schools. Such examples are described in detail in Xu and Rybach (2005). Operational experience is analyzed and the positive results reported in Xu and Rybach (2006).

By the end of 2007 the successfully operating HYY SWS installations in various parts of China comprised 330 systems with more than 5,512,253 m^2 total building space area and a wide range of building types and purposes:

- residential buildings (with a total of 1,902,068 m^2),
- administration buildings (1,943,016 m^2),
- hotels (359,892 m^2),
- shopping centers (315,952 m^2),
- schools (422,874 m^2),
- hospitals (62,449 m^2),
- factories (91,243 m^2),
- barracks (169',34 m^2),
- palace buildings (3,499 m^2),
- library (13,066 m^2),
- exhibition centre (110,207 m^2),
- kindergarten & senior homes (28,391 m^2),
- miscellaneous other (about 99,462 m^2).

Besides the widespread systems in China there is the beginning of dissemination abroad: HYY SWS installations are in operation and/or construction in Mongolia and USA.

Special attention deserves the HYY Single Well Systems deployed at the Beijing Olympic Games 2008. Various buildings and installations are supplied by HYY SWS, see Table 3.

TABLE 3. Facilities of the 2008 Beijing Olympic Park, supplied by HYY SWS installations.

Facility	**Area m^2**
Olympic Village National Gymnasium	80000
Athlete Mansion Hotel & Scientific Research Building	64382
Tennis Centre	26541
Hockey Training Facility in Beijing Lucheng Sports School	11851
Bicycle Training Facility in Beijing Lucheng Sports School	6049
National Great Theatre Waterscape	35000
Water antifreeze facility in a pool near the National Swimming Center	3000

4.4 Environmental benefits

The HYY SWS, like many other heat pump-based heating systems, has the advantage of avoiding the emission of CO_2 and other unwanted or polluting substances. Impressive numbers result from a comparison, performed for the Beijing area: with a total building space of 4'398'178 m^2 heated by

HYY SWS (as of end 2007) enables –compared to conventional coal fired systems– the saving of $2.7*10^5$ tons of coal per year and to avoid annually the emission of $2.3*10^9$ m^3 of exhaust fumes, $2.0*10^4$ tons of fine particles, $8.8*10^3$ tones of SO_2, $2.8*10^4$ tons of NO_X, and $4.2*10^5$ tons of CO_2.

5. CONCLUSIONS

Geothermal heat pumps (GHP) represent nowadays the fastest growing branch in the utilization of geothermal energy. The promoting factors are manifold: technical, economic, environmental awareness, governmental support. The most important driving force is knowledge and know-how. Therefore information/outreach to decision makers, politicians, professionals, as well as to the general public is of paramount importance. Besides, various applications and wide-scale realizations, high-level quality assurance and successfully operating facilities are of great help in order to trigger and sustain market demand.

In Switzerland the powerful interplay of the promoting factors result in remarkable increase rates: the installed capacity of GHP facilities increased from 1996 – 2006 by more than 300%. In China the innovative approach of a powerful groundwater heat pump system is increasingly applied to a great variety of building types, including several facilities at the 2008 Beijing Olympic Park.

The use of GHP systems represents an important contribution of renewable energies to the mitigation of climatic warming: the increasing use of the environmentally friendly geothermal technology enables the saving of great amounts of fossil fuels, avoid corresponding CO_2 emissions and, in the case of the application of GHP systems in building renovation, it results in a significant emission reduction. It can be expected that GHP systems, along with other geothermal technologies (especially for power generation), will further increase the benefits to future generations.

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