

Geothermal Fields Suitable for Power Generation

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Turkey is located on the Mediterranean sector of Alpine-Himalayan Tectonic Belt with many grabens, acidic volcanism, hydrothermal alteration zones, numerous hot springs and fumaroles. The data gathered since 1962 indicate that Turkey has a high geothermal energy potential. By comparison, it is among the first seven countries in abundance of geothermal resources around the world, while the share of its potential used is only about 2%. This means that considerable studies on geothermal energy could be conducted in order to increase energy supply and to reduce atmospheric pollution in Turkey. The main objective of the present study is threefold, namely: (1) to overview Turkey's geothermal fields suitable for power generation together with their possible utilization opportunities, (2) to present problems encountered and research projects developed in the Denizli-Kizildere geothermal field with an estimated capacity of 200 MW_e and (3) to assess the current status of geothermal energy use for electric energy production in Turkey. The Denizli-Kizildere geothermal power plant with an installed capacity of 20.4 MW_e, which is, at present, the only operating geothermal power plant of Turkey, was put into operation in 1984, while electricity from geothermal energy has been produced commercially since 1913. This plant produced on average an electrical energy of 84,920 MWh in the period between 1998–2001,

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representing an average electric power of 10.45 MW_e in the same period. Parallel to the development of the geothermal energy utilization in the country, it is projected that, by the years 2010 and 2020, the total geothermal power installed capacity will increase to 500 MW_e and 1000 MW_e, respectively.

Keywords geothermal energy, geothermal fields, electricity generation, power generation, power plant, renewable energy, Kizildere, Turkey

In a number of countries in Europe and worldwide, there is a growing interest in so-called green pricing schemes. The term 'green pricing' is generally understood to describe a program in which customers volunteer to pay more than their regular electricity bill, the additional amount being spent to promote renewable energies. There are other market-oriented schemes for the promotion of renewable energies such as the introduction of quotas, which may be traded. In this context, electricity gained from renewable sources is termed 'green electricity'. The main sources for this green electricity; wind, sun and small hydropower, suffer from cost and availability problems. Geothermal energy, by its nature, has a high availability because the source is not dependent on weather conditions. The awareness of geothermal energy as a possible source of electricity, however, is limited to countries with high enthalpy geothermal sources (Bruhn, 2002).

Geothermal utilization is commonly divided into two categories, namely electric energy production and direct use. Direct or non-electric utilization of geothermal energy consists of various forms for heating and cooling. The major areas of direct use applications are as follows: (a) swimming, bathing and balneology, (b) space heating and cooling including district heating, (c) agriculture applications, (d) aquaculture applications, (e) industrial processes, and (f) heat pumps. In general, the geothermal fluid temperatures required for direct use are lower than those for economic electric power generation (Lund, 1997).

Minimum production temperatures in a geothermal field generally required for different types of uses are characterized by the Lindal diagram, of which modified form is given elsewhere in detail (Lund, 1997; Fridleifsson, 1998). Conventional electric power production is limited to fluid temperatures above 150°C, but considerably lower temperatures can be used in binary cycle systems, also called organic Rankine cycles. In this case the outlet temperatures of the geothermal fluid are commonly above 85°C (Barbier, 2002).

Huttrer (2000, 2001) has reviewed the world-wide application of geothermal energy for power generation and reported the following: (a) geothermally-fueled electric power is being generated in 21 nations as of February 2000, (b) the installed capacity has reached 7974 MW_e, which is a 16.7% increase since 1995, (c) the total energy generated during the last 5 years has been at least 49,261 GWh, and (d) about 1165 wells more than 100 m deep have been drilled. Huttrer (2001) also concluded that greater increases in the total international installed geothermal generation capacity were inhibited by the economic crisis that occurred in southeast Asia, by the low petroleum prices that prevailed during the 5 year period from 1995 to 2000, and by serious capacity declines at The Geysers field in California, USA.

The share of the top three countries, namely the US, Philippines, and Italy, in total installed capacity of 7974 MW_e in 2000 (with the generation of 49.3 billion kWh in the same year) was about 27.94%, 23.94% and 9.8%, respectively, followed by Mexico at 9.47%, Indonesia at 7.39%, Japan at 6.85%, New Zealand at 5.48% and others at 9.13%. By comparison, Turkey accounted for about 0.256% of the total (Huttrer, 2001; Barbier, 2002).

In this study, Turkey's geothermal fields suitable for power generation are given first. The Denizli-Kizildere geothermal field (DKGF), where Turkey's first and, at present, only

operating geothermal power plant was installed in 1984, is then investigated. Finally, problems encountered and research projects developed in this field are presented.

Turkey's Geothermal Fields Suitable for Power Generation

The main geothermal provinces in Turkey may be classified by taking into account the tectonic and volcanic features such as: (a) high and moderate enthalpy fields situated on the graben structure of western Anatolia, (b) the low enthalpy fields on the north Anatolia fault zone related to strike-slip fault and volcanic activity, (c) geothermal systems on the sedimentary basin mainly related to volcanic activity, and (d) systems in mountainous terrain related to volcanism and compression tectonics (Aires-Barros, 1997).

Table 1 illustrates nine geothermal fields of Turkey suitable for generating electricity together with their possible utilization opportunities. High temperature geothermal fields suitable for conventional electricity generation are as follows: Denizli-Kizildere (200–242°C), Aydin-Germencik (232°C), Aydin-Salavatli (171°C), Canakkale-Tuzla (173°C), Kutahya-Simav (162°C) and Izmir-Seferihisar (150°C). The number of the wells in the two geothermal fields, Denizli-Kizildere and Aydin-Germencik, is relatively more than that of the remaining fields. Besides this, geothermal wells drilled are insufficient in the other seven geothermal fields. Therefore, the studies on the determination of the potential of these fields are still in progress (Gunerhan et al., 2001; Akkus et al., 2002).

The only operating geothermal power plant of Turkey is the Denizli-Kizildere geothermal power plant (DKGPP) located near the province of Denizli in Western Anatolia with an installed capacity of 20.4 MW_e. The total capacity of the field is estimated to be 200 MW_e (Gunerhan et al., 2001).

The exploration stage is completed in Aydin-Germencik field, which is located on the west of Kizildere. Nine wells have been drilled into a 216–232°C reservoir within marbles and quartzites at depths ranging from 285–1500 m. The field capacity is estimated to be 100 MW_e. The first stage of the field development is planned to build a 25 MW_e single flash plus binary power plant (GRC, 1998).

The third field with power generation potential is Canakkale-Tuzla Field in northwest Anatolia. The first well was drilled in 1982. The temperature encountered was 174°C in a reservoir at a depth of 333–553 m in volcanic rocks. A second well was drilled to 1020 m. Temperatures up to 174°C were recorded, but permeability was low. Another two shallow wells (81 and 128 m) also produced fluid at 146 and 165°C.

The Aydin-Salavatli field has a reservoir temperature of 171°C. A 5 MW_e binary or kalina cycle plant with greenhouses or process hot water supply to the industries surroundings was planned in the field but have not realized yet (Tufekcioglu, 1999).

There are also plans to generate 500 MW_e from Germencik, Kizildere, Canakkale and several of the other fields by the year 2010 and 1000 MW_e by 2020 (Huttrer, 2001).

Denizli-Kizildere Geothermal Field

Brief Historical Development

Electricity generation from geothermal steam dates back to the beginning of the last century. In fact, commercial generation of electricity from geothermal steam began in Larderello, Tuscany, Italy in 1913, with an installed capacity of 250 kW_e. However, the first experiments to make use of natural steam to generate electricity date back to 1904, when Prince Piero Ginori Conti coupled a steam-engine to a dynamo to light five bulbs in his boric acid factories at Larderello. Since 1950, other countries have followed the

Table 1
Main geothermal fields suitable for electricity in Turkey and possible utilization opportunities

Item no.	Name of geothermal field	Temperature (°C)	Current utilization	Possible utilization opportunities
1	Denizli-Kızıdere	242	Electricity generation, greenhouse heating, space heating, simple balneology applications, CO ₂ production, weaving industry	Electricity generation, building heating and industrial applications, drying, thermal tourism, thermal facility heating, and cooling applications.
2	Aydin-Germencik	232	Greenhouse heating of 0.05 ha	Electricity generation, district heating and cooling, greenhouse, drying, textile industry, cold stores, thermal tourism and thermal facility heating
3	Canakkale-Tuzla	174	Greenhouse heating, space heating, simple balneology applications, salt production.	Electricity generation, thermal tourism and thermal facility heating and salt production.
4	Aydin-Salavatlı	171	Thermal tourism	Electricity generation, district heating and cooling, greenhouse heating, drying, industrial process heat, thermal tourism and thermal facility heating.
5	Kutahya-Simav	162	Thermal tourism, thermal facility heating, greenhouse heating of 12 ha, district heating with the residences of 3200.	Electricity generation, thermal tourism, thermal facility heating, greenhouse heating, industrial applications, district heating application at Simav, industrial use.
6	Izmir-Seferihisar	153	Simple balneology applications, greenhouse heating of 0.6 ha at Seferihisar	Electricity generation, thermal tourism, thermal facility heating, district heating, greenhouse and industrial facility heating.
7	Manisa-Salihli-Caferbey	150	District heating application of 200 residences at Salihli	Electricity generation, thermal tourism, thermal facility heating, drying.
8	Aydin-Yılmazkoy	142	Not available	Electricity generation plus integrated use.
9	Izmir-Dikili	130	Simple balneology applications, greenhouse heating of 1 ha	Electricity generation plus integrated use.

Source: Gunerhan et al. (2001), Akkus et al. (2002), Hepbasli and Canakci (2002).

Italian example, and at present electricity is generated from geothermal energy in 21 countries all over the world (Barbier, 2002). The first power plant based on geothermal hot water has been in operation in Wairakei, New Zealand since 1958 (Barbier, 1997; Bruhn, 2002).

The DKGf is located in 30 km away from the province of Denizli, Western Anatolia, Turkey, while it is the first and only one geothermal field developed in Turkey. Hot springs and fumaroles exist around the field at a wide range of temperature of 30–100°C.

The evolution in time of the DKGf can be summarized as follows:

- The first geological, geochemical and geophysical studies were performed with support of the United Nations Development Program (UNDP) in 1966.
- The first well was drilled in 1968 with a temperature measured of 198°C at a depth of 540 m. A total of 14 wells were drilled between 1968–1973 and the temperatures obtained were in the range 170–212°C.
- A 0.5 MW_e pilot plant was installed in 1974 in the field. The electricity generated had met demand of the villages around the field for a long time period. The General Directorate of Mineral Research and Exploitation (MTA) reported that 6 out of 13 wells were suitable for generating electric power.
- The DKGPP was installed in 1984 with an installed capacity of 20.4 MW_e. Then, three more production wells were drilled in two years, reaching a total of nine production wells (Sarikurt, 1983). Two stratigraphically separate zones in the field were initially identified as first and second reservoirs during the exploration stage. Shallow reservoir has a temperature of 190–200°C, a depth of up to 706 m, a steam fraction of 10% and a moderate permeability. Besides this, the deeper one has a temperature of 200–212°C, a depth of up to 1241 m, and a steam fraction of 10–12% and a higher permeability. So, the second reservoir was chosen as production zone.
- In Turkey, the first greenhouse heating system of 0.45 ha by geothermal energy was applied in the DKGf in 1985.
- Because of high non-condensable gas (NCG) content of the field (average 13% by weight of the steam) and since NCG's consist mainly of CO₂ (96–99%), a liquid CO₂ and dry ice production process with an annual capacity of 40,000 tons was built adjacent to the field in 1986. The capacity of the process was increased to 120,000 tons annually in 1999. Besides electricity and dry ice production, the resources of the field have also been used for greenhouse heating and space heating of offices and staff houses of the plant (Simsek, 1985; Simsek and Demirel, 1998).
- In 1997, the so-called R-1 well was drilled for injection purposes. This well intersected a deeper zone (2261 m) with a temperature of 242°C and a steam fraction of 16–18%. The completion tests showed that the well has a high productivity with the values of 103.05 kg/s and 6 MW_e (Serpen and Satman, 2000). This well indicated that a third reservoir with a temperature range of 235–245°C exists in the DKGf.
- Starting from the commissioning of the plant, the wastewater of the plant had been discharged to the Menderes river with a flow rate of 1000 t/h and a temperature of 147°C. In 1986, it had planned to use this waste heat (about 140 MW_{th}) to heat the Denizli city but the pre-feasibility studies have resulted uneconomic in terms of the distance (33 km) and altitude difference (200 m) between the field and the city. The project has been actualized in 2001 and the source was considered as a good prospect for Saraykoy town, which is 5 km away from the field. Geothermal

fluid at separator exit will be sent to a heat exchanger to transfer its energy to the city circulation water. Then a 9-km long pipeline at a flow rate of 194.5 kg/s will carry the clean city water.

- Today, the DKGPP employs 98 people including engineers, technicians and workers, while it operates 8000 h/yr. The rest is spent for maintenance works such as cleaning the wells and overhaul. Electricity production cost in 2001 was calculated to be 1.75 cents/kWh.

Main Characteristics

Main characteristics of the DKGf and DKGPP are given in Table 2 (Sarikurt, 1983; MTA, 1996; Gunerhan, 2000; TEAS, 2002). The DKGf is a liquid dominated system with a steam fraction of 10–12%. Steam field area is 550 m × 650 m, while the calculated reservoir area is 100 km². The depth of the wells changes from 370 m to 2261 m. Reservoir temperature is 200–242°C. Estimated capacity of the field is 200 MW_e. The most significant characteristic of the field is the high amount of non-condensable gases (2.5% in the reservoir, 5% by volume of steam, 10–20% by weight of steam and average 13% by weight of steam at the turbine inlet) with a CO₂ content of 96–99%, H₂S content of 100–200 ppm and NH₃ content of 72 ppm (MTA, 1996). Specific steam consumption of the plant is 10.96 kg/kWh, while the first law efficiency of the plant is determined to be 11.98%.

Only 10–12% of brine extracted from the ground turns into steam after the separation process and the remaining 88–90% had been disposed to the Menderes river by a 1.8-km long channel at an average 147°C temperature and a total flow rate of 277.7 kg/s from 1984–2002.

Table 2
Some characteristics of the Kizildere geothermal field and plant

Description	Unit	Value
Reservoir temperature	°C	200–242
Wellhead steam fraction	%	10–12
Total dissolved solid (TDS)	ppm	2500–3200
CO ₂ partial pressure	MPa	3.0–5.0
NCG content in steam (by wt)	%	10–21
CO ₂ content	%	96–99
H ₂ S content	ppm	100–200
Number of production wells		9
Optimum wellhead pressure	MPa	1.6 (because of scaling)
Wellhead operation pressure	MPa	1.28–1.58
Wellhead temperature	°C	180–190
Total flow rate	kg/s	320.83
NCG flow rate	kg/s	6.1345
Installed capacity	MW _e	20.4
Gross capacity	MW _e	14.0
Net capacity	MW _e	11.2

Source: Sarikurt (1983), MTA (1996), Gunerhan (2000), TEAS (2002).

Injection System

The commonly acceptable method of dealing with wastewater is to inject it back into a part of the reservoir.

The first pilot injection test in the DKGf was conducted in 1976 and lasted for 29 weeks. The water produced from well KD-15 was injected into well KD-1A at an average rate of 23.61 kg/s. Injected water temperature varied from 70°C to 80°C. Well KD-1, which is 68 m away from KD-1A, was chosen as the observation well. The cooling effect was encountered at the observation well. A heat flow model describing the non-isothermal fluid flow in naturally fractured reservoirs is applied and the temperature behavior in the observation well is predicted.

The second test lasted for 45 days in 1995. The water produced from KD-20 was injected into well KD-7 by gravity. The wellhead injection temperature was 100°C. Decline in injectivity is related to the possible plugging by scale deposition in the injector. The producer KD-20 also served as an observation well for monitoring the produced water temperature and chloride (Cl^-) concentration. Some change in the chloride content but no change in the temperature of the produced water was observed. Due to the limitations in technical conveniences at that time the actual reasons of plugging difficulty have never been revealed (Satman et al., 2000).

After those trials, an injection well (TH-2) was designed to drill on the other side of the Menderes river, in the Tekkehamam field, which is 3 km away from the DKGf. The injectivity of the well was poor hence it was abandoned.

Regarding with the injection program of the MTA, another injection well (R-1) was drilled in the DKGf boundary in 1997. The completion tests indicated that the well has high productivity, 103.05 kg/s and 6 MW_e, and the highest temperature in the field with a bottom hole temperature of 242°C at 2261 m. Regarding the data obtained, R-1 well was converted to a production well in 2001 and the production of the plant increased by 6.5%.

Following R-1 well drilling, the MTA conducted some injection trials at abandoned wells in the field in 1998–99, but very fast temperature dropdown was observed in production wells. In 2000, a new injection well (R-2) initiated to drill and completed in 2001 with a depth of 1371 m.

Injection trials in R-2 had been conducted for three months, from May to August 2002. Separated liquid from 2 production wells at 55.55 kg/s flow rate and a temperature of 125–135°C was injected by gravity. The results of the trials have not been reported yet.

Based upon the injection strategy recommended by Serpen and Satman (2000), the Denizli-Kizildere system would produce from the deeper and hotter third reservoir and inject to the shallow reservoir. Since the third reservoir produces more steam than the second reservoir, which is used as production zone, the amount of water to inject will decrease approximately by half.

Problems Encountered in the Field

Scaling

One of the severe problems of the field is scaling problem. In the production wells, precipitation of CaCO_3 due to decrease in partial pressure of CO_2 occurs; in the injection wells, precipitation of Si due to temperature dropdown occurs (Giese, 1998). In the field, to solve scaling problem, acid, Dequest 2006 inhibitor and CO_2 injection tests were planned and

only acid and inhibitor injection tests were conducted for 10 months in 1988–1989. The results were successful but because of the high operational cost and contamination potential on groundwater of such applications, mechanical cleaning of the wells once a year was preferred. Production of the wells reaches maximum after cleaning and decreases gradually between two cleaning periods because of the decreasing diameter of the well. Besides cleaning, to reduce the scaling rate, optimum wellhead pressures were determined for each well and the wellhead pressures are kept as high as 1.1–1.94 MPa, but the plant still generates only about 70% of its installed capacity. The studies indicated that if inhibitors were used, power generation would increase by 25% (Serpen and Satman, 2000).

Pressure Drop

The mass balance of the field indicated that production rate exceeds the natural recharge rate of the field. Besides this, during 18 years of operation, injection had not been practiced. As a result of lack of injection and overproduction, in an area of 0.06 km² in the middle of the field, a pressure drop of 0.05 bar/a (–5m) was encountered (Giese, 1998).

Environmental Problems

Drainage into the Menderes river causes environmental problems due to the heat load and the chemicals in the fluid, especially boron (B).

High boron content of the discharged fluid threatens the agriculture in the region. The wastewater reaches to the river with a boron content of 25 ppm. The river is used for irrigation of the Menderes plain, and especially in summer time when the flow rate of the river is low, boron concentration exceeds the upper limit of 1 ppm for irrigation. Injection becomes essential in the field for environmental concerns and reservoir stability.

The DKGFP contains a high amount of CO₂, which cause a greenhouse effect globally. In Kizildere, CO₂ is not rejected to the atmosphere; instead it is extracted as liquid CO₂ and dry ice in a plant adjacent to the power plant as an industrial application. H₂S content in the field is under the exposure limits.

Research Projects Developed in the Field

Upstream Reboiler Tests

The power needed to extract the NCG's from the condenser and discharge them into the atmosphere is supplied by the electricity produced, which seriously impairs the power generation performance (Duthie and Nawaz, 1989). A research project was conducted to remove NCG's from geothermal steam upstream from the turbine to decrease the compressor consumption and increase power plant efficiency. A bench scale experimental unit was set up and tested in the field in 1999. Calculations gave a 35.3% reduction in parasitic load of the plant, increasing the net capacity by 10.6% (Gunerhan and Coury, 1999; Gunerhan, 2000).

Boron Removal Tests

The wastewater of the DKGPP contains boron at approximately 30 ppm. The level of boron is high to be used for irrigation in agricultural areas. High concentrations of boron are particularly detrimental for citrus fruits. Therefore, the permitted level of boron in

irrigation water is 1 ppm. To prevent discharge of boron to the Menderes river and to investigate the possibilities of economical boron extraction, some research projects were developed in the field.

Recepoglu and Peker (1991) investigated boron removal from the DKGf wastewater using the boron selective resin Amberlite IRA 743. In the case of Kizildere, with wastewater with a pH of 8.9 and high HCO_3 content, single stage regeneration was found to be feasible and the exhausted resin was found to be regenerated economically. Boron removal after a single stage regeneration with 10% H_2SO_4 was found to be possible.

This work was followed by Badruk et al. (1999a,b) and chelating ion exchange resins Diaion CRB 02 and Purolite S 108 were performed on a quantitative removal of boron from wastewater of the KGF in 1998–1999. Preliminary column tests showed that Diaion CRB 02 is a potential resin for column removal of boron from wastewater of geothermal power plant (Badruk et al., 1999a). Column sorption-elution method was tested as well by Badruk et al. (1999b). The column performances of the same resins for boron removal were observed. N-glucamine type resins Diaion CRB 02 and Purolite S 108 were found to be promising for column removal of boron. It was concluded that a certain emphasis should be given on developing cheaper ion exchange resins with a higher capacity than the resins employed in this work for a cost effective process in which technical objectives are obtained (Badruk et al., 1999b).

Denizli-Kizildere Geothermal Power Plant

Based on the values for wells drilled, Turkey's geothermal power production potential is estimated to be 764.81 MW_e (Akkus et al., 2002).

The DKGPP is a single flash system with a condensing low-pressure double-flow turbine. This plant operates with a 90% load factor, while it is described in detail elsewhere (Gunerhan, 2000).

Electricity generation of the DKGPP is illustrated in Figure 1 (TEAS, 2002). As can be seen in this figure, the plant produced on average an electrical energy of 84,920 MWh

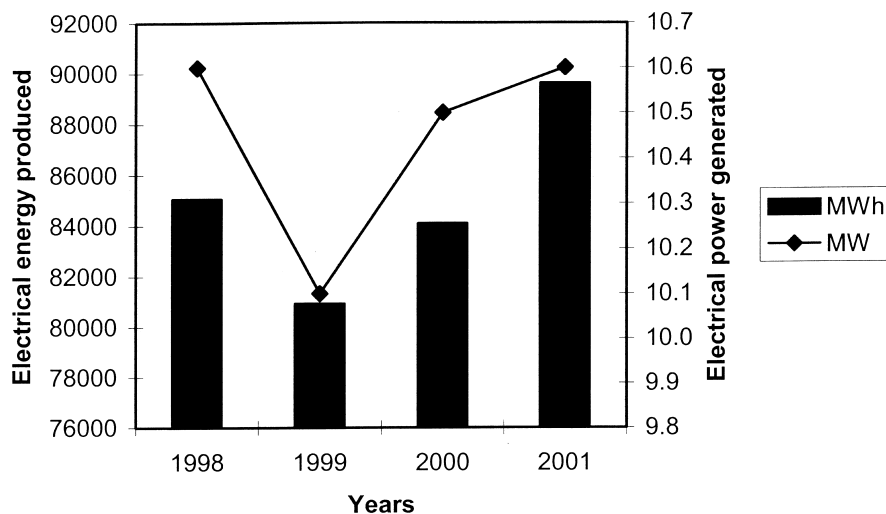


Figure 1. Electricity generation of the Denizli-Kizildere power plant between 1998–2001. *Source:* TEAS (2002).

in the period between 1998–2001, representing an average electric power of 10.45 MW_e in the same period.

Conclusions

Geothermal utilization is commonly divided into two categories, namely electric energy production and direct (or non-electric) uses. This study focused on the former, namely power generation. The main conclusions derived from the present study may be summarized as follows:

- In Turkey, there are nine geothermal fields suitable for generating electricity.
- Based on the values for wells drilled, Turkey's geothermal power production potential is estimated to be 764.81 MW_e.
- The only operating geothermal power plant of Turkey is the Denizli-Kizildere geothermal power plant with an installed capacity of 20.4 MW_e and an average electric power produced of 10.45 MW_e between 1998–2001. The total capacity of the field is estimated to be 200 MW_e.
- Geothermal wells drilled to date in Turkey, having 170 geothermal fields, are few in numbers. More geothermal wells should be drilled for extending geothermal applications throughout the country.
- There is not any 'geothermal law in Turkey', as yet. There is, however, a 'draft geothermal law'. It is expected that geothermal energy development will significantly increase in the country if this law becomes effective.

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