PERSPECTIVES OF GEOTHERMAL DEVELOPMENT IN ITALY AND THE CHALLENGE OF ENVIRONMENTAL CONSERVATION

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ABSTRACT

The status of geothermal development for power generation in Italy as of the end of 1996 is presented. Future development is dependent upon the acceptance of local residents; environmental conservation and socio-economic aspects have thus become fundamental issues in ENEL activities.

The results of an environmental assessment study carried out in the Mt. Amiata area, where several plants are in operation and others are planned, are outlined. Pollutant concentrations are well within the limits set by current legislation; however, H_2S and mercury abatement is planned to avoid the odor nuisance of H_2S and possible adverse effects from mercury buildup in the long term.

The scheme for combined hydrogen sulfide and mercury abatement, developed for the particular characteristics of Italian geothermal fluids, is described. The proposed technology is going to be demonstrated on a pilot scale and then on a 20 MW power plant.

INTRODUCTION

The potential of geothermal development in Italy is generally considered large in terms of low-temperature resources (<130°C) and moderate in terms of resources suitable for electricity generation. ENEL's efforts have been mainly directed towards the research and the subsequent utilization of the latter type of resources, but in the last few years increasing attention has been dedicated to direct uses of geothermal heat and to industrial use of by-products associated with geothermal fluids.

As far as electricity generation is concerned, slow but steady development is under way, together with renewal of older power plants built immediately after WW II and in the 1950s. As of 31st December 1996, the installed capacity was 742.2 MW, around 150 MW of which is made up by old plants kept as a reserve; the gross generation in 1996 calendar year was 3,762 GWh. These figures can be compared with the situation at the end of 1994, presented at the WGC held in Florence (Allegrini *et al.*, 1995): 625.7 MW and 3,417 GWh, respectively.

Detailed data on capacity and electricity generation of each unit are shown in Table 1. With respect to the previous situation, one unit was dismantled (Bagnore 1, rated 3.5 MW) and four new units came on line (Farinello, 60 MW, and the three 20 MW units of Piancastagnaio 5, Nuova Sasso and Le Prata). Farinello power plant completed the renewal of the central part of the Larderello field, where three 60 MW units are now installed (with Larderello 3 as a reserve), while Nuova Sasso and Le Prata replaced Sasso Pisano and a unit in Serrazzano power plant, respectively.

Direct uses of geothermal heat have been increasing at a slower rate, mainly due to the competition of low-cost fossil fuels and to the lack of financial support for geothermal direct uses aimed at balancing the so-called "externalities" (or social costs) associated with the use of fossil fuels but not included in their market price. However, new district heating systems went into operation in some villages in the Larderello area (Montecerboli, Serrazzano and Sasso Pisano) and others are planned at Mt. Amiata. In addition, a couple of industrial plants utilizing geothermal heat are under construction in the Travale-Radicondoli area.

Table 1 Utilization of geothermal energy for electricity generation as of December 1996

Geothermal Field	Power Plant	Unit	Year Commissioned	Status	Type of Unit	Unit Rating: Operating or Reserve MW$_e$	Unit Rating: Under Constr. or Planned MW$_e$	Annual Energy Prod. (1996) GWh/yr
Larderello	Larderello 3	1	1965	R	DS-C	24		-
		2	1950	R	DS-C	24		13.7
		3	1964	R	DS-C	26		-
		4	1965	R	DS-C	24		5.9
	Farinello	1	1995	O	DS-C	60		354.8
	Castelnuovo V.C.	1	1946	O	DS-C	11		10.5
		2	1948	R	DS-C	11		-
	Gabbro	1	1969	O	DS-C	15		120.7
	Valle Secolo	1	1991	O	DS-C	60		470.9
		2	1992	O	DS-C	60		482.7
Radicondoli	Pianacce	1	1987	O	DS-C	20		127.3
	Rancia	1	1986	O	DS-C	20		114.4
	Rancia 2	1	1988	O	DS-C	20		132.5
	Radicondoli	1	1979	O	DS-C	15		105.6
		2	1979	O	DS-C	15		94.4
Lago	Lago	1	1960	O	DS-C	6.5		33.2
		2	1960	R	DS-C	12.5		-
		3	1964	O	DS-C	14.5		32.5
	Cornia	1	1987	O	DS-C	20		115.7
	Cornia 2	1	1994	O	DS-C	20		109.2
	San Martino	2	1985	O	DS-C	20		119.1
		3	1988	O	DS-C	20		131.4
	Molinetto 2	1	1982	O	DS-C	8		62.4
	La Leccia	1	1983	O	DS-C	8		65.2
	Lagoni Rossi 3	1	1981	O	DS-C	8		54.0
	Monterotondo	1	1958	O	DS-C	12.5		104.2
	Sasso Pisano	1	1958	R	DS-C	12.5		14.5
		2	1958	R	DS-C	3.2		-
	Nuova Sasso	1	1996	O	DS-C	20		92.2
	Serrazzano	1	1957	R	DS-C	12.5		85.5
		2	1957	O	DS-C	12.5		85.3
		5	1975	O	DS-C	15		91.1
	Le Prata	1	1996	O	DS-C	20		38.1
	Monteverdi 2	1		UC	DS-C		20	
	Monteverdi 1	1		P	DS-C		20	
	Carboli 1	1		P	DS-C		20	
	Carboli 2	1		P	DS-C		20	
	Selva 1	1		P	DS-C		20	

Geothermal Field	Power Plant	Unit	Year Commis-sioned	Status	Type of Unit	Unit Rating Operating or reserve MW$_e$	Unit Rating Under Constr. or Planned MW$_e$	Annual Energy Prod. (1996) GWh/yr
Mt. Amiata	Bagnore 2	1	1962	O	DS-D	3.5		-
	Bagnore 3	1		UC	DS*-C		20	
	Piancastagnaio 2	1	1969	O	DS*-D	8		34.8
	Bellavista	1	1987	O	DS*-C	20		67.1
	Piancastagnaio 3	1	1990	O	DS*-C	20		149.9
	Piancastagnaio 4	1	1991	O	DS*-C	20		121.5
	Piancastagnaio 5	1	1996	O	DS*-C	20		121.8
	Piancastagnaio 6	1		P	DS*-C		20	
	Piancastagnaio 7	1		P	DS*-C		20	
	Piancastagnaio 8	1		P	DS*-C		20	
Latera	Latera	1		UC	2F		20	
		2		UC	2F		20	
		3		UC	B		2.5	
		4		UC	B		2.5	
	Marta	1		UC	B		2.5	
TOTAL		53(*)				**742.2**	**207.5**	**3762.4**

STATUS: O=Operational
R= Reserve capacity
UC= Under construction
P= Planned
(*) 30 O + 9 R; 7 UC + 7 P

TYPE OF UNIT: DS= Dry steam
DS*= Entrained water separated at wellhead
C= Condensing
D= Discharging-to-atmosphere
2F= Double flash
B= Binary

Increased use of the noncondensable gas associated to the geothermal fluid for CO_2 recovery is foreseen (one plant is already in operation in the Torre Alfina field, with a capacity of over 30,000 metric tons/year), together with the exploitation of Cesano hypersaline brine for the extraction of potassium salts.
An updated map of the geothermal localities of Italy, including a summary of the present status of the various types of utilization, is shown in Figure 1.

GEOTHERMAL DEVELOPMENT

Some of the areas where geothermal development is under way are located at the borders of the traditionally exploited fields of Larderello and Travale-Radicondoli, thus constituting an extension of them. This is the case for the areas of Monteverdi, Selva and Carboli, where power plants are under construction or planned (see Table 1) and for the southernmost area of Radicondoli, where an additional plant (Radicondoli 3) should be built in the future. However, it is felt that further expansions of these areas are unlikely.

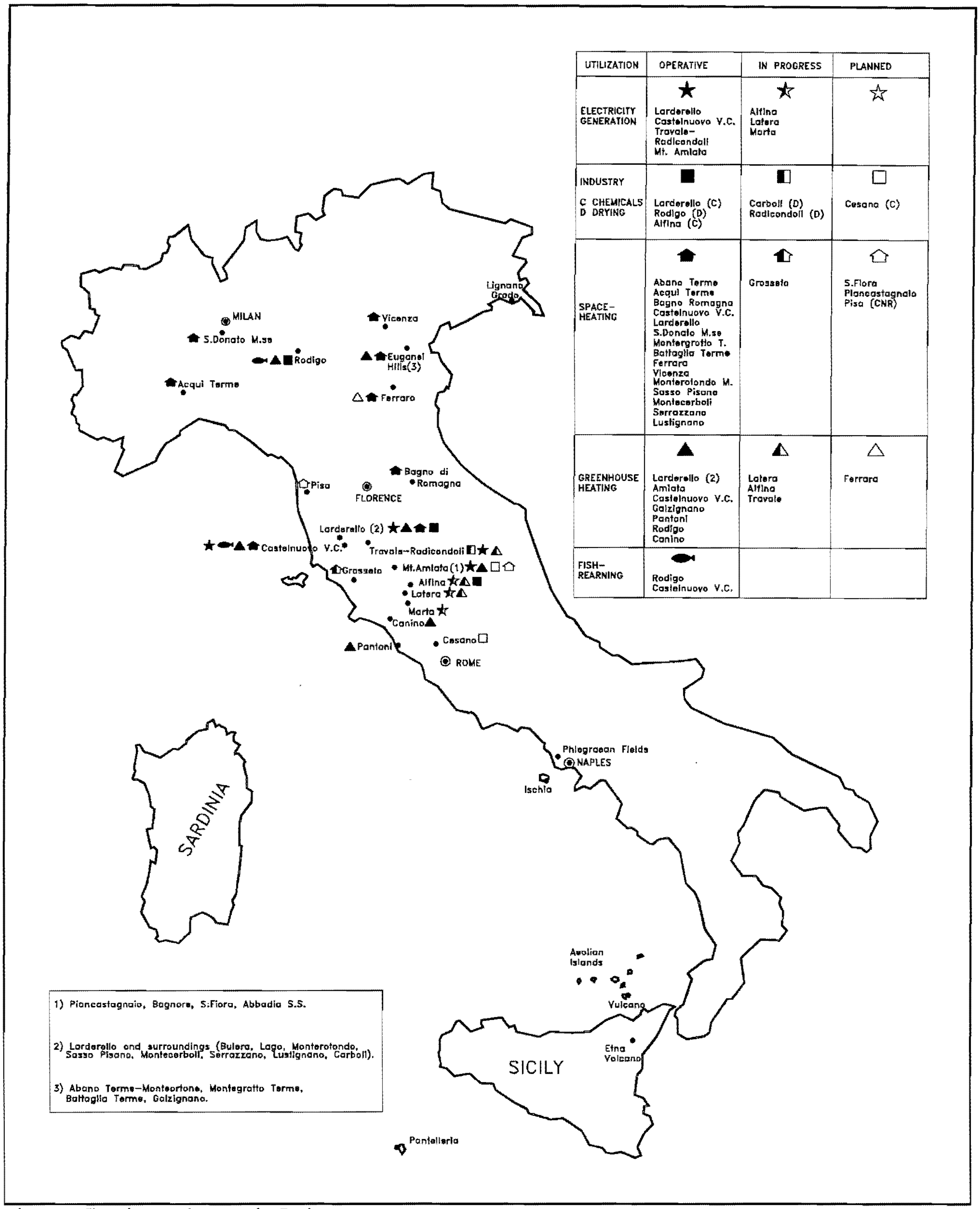

Fig. 1 Geothermal areas in Italy

Thus, the geothermal areas of Mt. Amiata and surroundings are of foremost importance for future geothermal development in Italy: apart from the plants yet to be built in the Piancastagnaio field (see Table 1), an extension of this deep reservoir has been ascertained at Abbadia San Salvatore (north of Piancastagnaio), and promising prospects exist for further development in the nearby areas.

It should be noted that these areas of expansion for geothermal power generation do not feature any kind of geothermal "tradition" like the long history of geothermal resources utilization at Larderello. As a result, geothermal development is often seen by most residents as a negative event, with potential risks of environmental damage and even harmful effects on health. The threat posed by geothermal operations to the environment as perceived by local inhabitants is reinforced by the fact that the above areas are rich in natural beauty and almost unspoiled by any kind of industrial development.

In the present situation, characterized by increasing environmental concern, it is clear that geothermal development can no longer be carried out without the acceptance of most residents. Thus, in order to make geothermal development acceptable, ENEL has to face the difficult task of operating in the framework of tight environmental conservation.

The two main aspects of this challenge are related to landscape protection, involving steam pipelines and power plants, and to the reduction of pollutant emissions. The latter are dealt with in detail in the next part of this paper.

GEOTHERMAL POWER PLANT EMISSIONS AND EFFECTS ON THE ENVIRONMENT

Italian geothermal fields are characterized by an unusually high noncondensable gas (NCG) content, typically ranging from 4 to 10% by weight in the produced steam. Lower figures are seldom found (around 1% by weight for San Martino power plant), while even higher values can be present (some deep wells in the Piancastagnaio field, the shallow reservoir of Piancastagnaio and the separated steam from the Latera water-dominated field).

Most of the NCG is carbon dioxide (generally over 95% by weight); however, hydrogen sulfide is typically around 1%. Boron (in the form of boric acid) and trace elements are also present in the steam. Elemental mercury is mainly associated with the NCG, with values of up to several mg/Nm^3 in the Amiata area, where mercury ore (cinnabar) was mined until the early 1960s. Of lesser concern are the arsenic and antimony contents.

With the exception of Piancastagnaio 2 and Bagnore 2, featuring discharging-to-atmosphere turbines (Figure 2), all geothermal power plants are of the direct steam condensing type, equipped with direct-contact condensers (Figure 3). NCGs are extracted from the condenser by means of a centrifugal compressor (with intermediate gas cooling, again of the direct-contact type) and emitted to the atmosphere above the induced draft cooling tower in order to achieve better dispersion of the plume. The standard size of the new power plants is 20 MW (except at Larderello, where three 60 MW units were installed), requiring a supply of 110 t/h of fluid (Allegrini *et al.*, 1985).

Any entrained water associated with the steam (separated at wellhead) and the excess condensate from the cooling towers are both reinjected in the geothermal reservoir in order to prevent pollution of surface waters.

The main environmental (and health) concern associated with the operation of geothermal power plants arises from their airborne emissions: primarily from compressor NCG discharge (hydrogen sulfide, mercury and trace elements) and secondarily from water stripping and entrainment (drift) in the cooling towers (hydrogen sulfide, although to a lesser extent than in compressor exhaust, boric acid and trace elements).

An extensive study was commissioned by ENEL to ascertain the effects on the environment of the airborne emissions of Piancastagnaio geothermal power plants, thought to be the most representative ones, due to the high NCG content of the steam. An area of around 60 km^2 was involved, where the power plants Bellavista and Piancastagnaio 2, 3 and 4, with the associated production and reinjection wells, were in operation in the southern part, whereas in the northern part exploration activities only had been carried out.

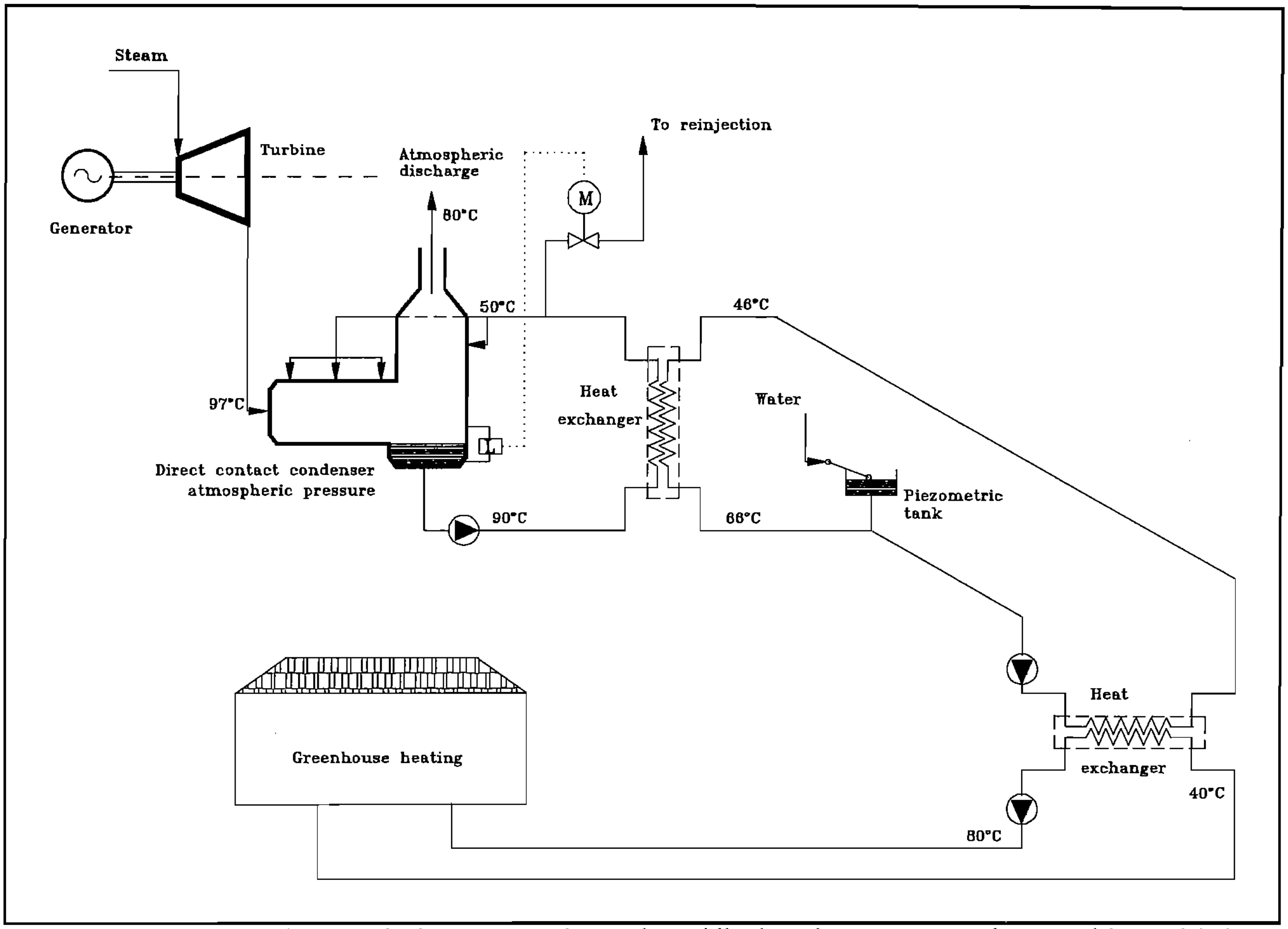

Fig. 2 Simplified scheme of Piancastagnaio 2 plant (discharging-to-atmosphere turbine with heat recovery).

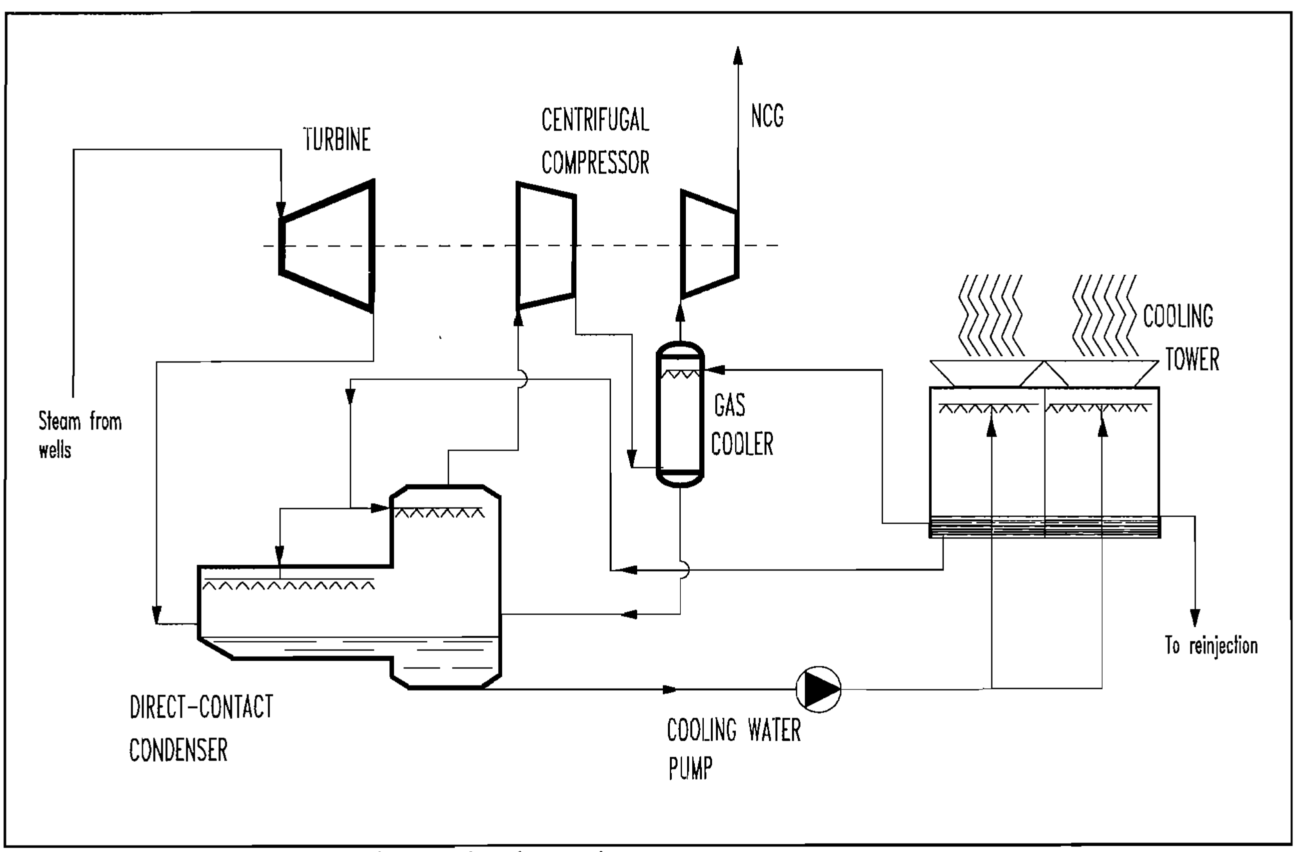

Fig. 3 Simplified scheme of a condensing unit.

Field surveys lasted more than one year and concerned the following topics:

- Air quality, with measurement of the pollutant concentrations (H_2S and Hg) in the ambient air, wet and dry precipitations and lichens, used both as bioindicators (determination of the index of air purity, IAP) and as bioaccumulators.
- Soil contamination, with chemical analyses of geothermal pollutants (Hg, As, Sb and H_3BO_3).
- Water quality, with analyses of water and sediments in watercourses.
- Characterization of vegetation, in order to check for any possible damage or adverse effect from geothermal activities.
- Contamination of vegetables and grasses (fodder plants), with chemical analyses of geothermal pollutants.
- Measurement of mercury emissions from old mining sites (where spoil banks of roasted cinnabar still exist).
- Measurement of the pollutants released to the atmosphere from geothermal power plants (H_2S, Hg, As, Sb and H_3BO_3).

Particular care was used in relation to this last point. In order to check data reliability and accuracy, a mass balance of the different chemical species was performed on each power plant, determining all input and output mass flow rates. Plant emissions are reported in Table 2, while Table 3 shows, as an example, the mass balance for Bellavista plant.

Table 2 Power plant emissions in Piancastagnaio area

	UNITS	POWER PLANT				
		PC/3	PC/4	BELLAVISTA	PC/2	
					Reduced flow rate w/o direct use	Max. flow rate with direct use
LOAD	MW_e	9.8	17.1	16.2	2.5	6.8
HYDROGEN SULFIDE	kg/h	106.8	144.8	185.3	95.2	135.8
MERCURY	g/h	65.1	35.1	36.1	53.9	123.8
ARSENIC	g/h	5.5	6.5	2.3	<1.5	N.M.
ANTIMONY	g/h	<0.7	<0.9	<0.6	<0.8	N.M.
BORIC ACID	kg/h	1.47	0.88	0.60	2.02	0.21

N.M.= Not measured

The main results can be summarized as follows:

- Almost all the H_2S entering the power plants is discharged to the atmosphere, as the reinjected fraction is less than 5%.
- The main H_2S emission source (65-70% of the total) is the NCG compressor exhaust, with the remaining part stripped out from the cooling tower.
- Mercury is mainly emitted together with the NCG, with small amounts (1.4-2.2 g/h) released by the cooling towers.
- Arsenic emissions are quite small; drift measurements seem to indicate that most of them (around 90%) are due to volatile compounds.
- Antimony emissions are even lower than arsenic, with concentrations near at or below the detection limit in most streams.
- Boric acid emissions, in the range 0.6-1.5 kg/h, are mainly due to the cooling tower drift.

Table 3 Mass balance at Bellavista power plant (Load: 16.2 MW_e)

	Units	INLET	OUTLET						OUTLET /INLET
			GASEOUS STREAMS			LIQUID STREAMS		TOTAL	
		Steam turbine inlet	NCG exhaust	Turbine drainage separator	Cooling tower	Turbine drainage separator	Reinjected condensate		%
Total flow rate	t/h	123.8	12.6	0.23		0.05	31.1		
Steam	t/h	112.9							
NCG	t/h	10.9							
H_2S	kg/h	200.0	127.3	0.03	57.9	0.0005	3.98	189.2	94.6
Hg	g/h	33.7	34.7	0.011	1.31	0.0003	1.18	37.2	110.3
As	g/h	16.39	1.37	0.014	0.81	0.58	17.03	19.81	120.9
Sb	g/h	3.58	<0.21	0.004	<0.33	0.002	2.24	<2.79	77.8
H_3BO_3	kg/h	87.50	0.12	0.024	0.31	0.61	74.9	75.99	86.8

The knowledge of the emission sources and of the meteorological and climatological features of the area (local weather data were recorded for many years by a dedicated ENEL station) allowed to model the ground level concentrations of the major pollutants, which were compared with the measured data.

The main conclusions of the study are undoubtedly positive: the overall environmental situation is good notwithstanding the tailings left by past mining activity and the emissions of geothermal power plants. All pollutants are present, at worst, in concentrations within the limits set by current laws and standards.

However, it was confirmed that, under certain meteorological conditions, hydrogen sulfide concentrations may reach values well above the odor threshold in the villages of the area, constituting a nuisance for the resident population and tourist resorts. Moreover, it was felt that mercury emissions, even if negligible as far as health effects are concerned, might represent an environmental threat in the long term. Of course, both effects could be worsened by the installation of new power plants in the area.

HYDROGEN SULFIDE AND MERCURY ABATEMENT

According to the results of the environmental study outlined above, it was concluded that geothermal development might be made sustainable and acceptable by the local residents only adopting a new approach, where environmental conservation and socio-economic aspects represent fundamental issues.

ENEL is looking at ULEV (Ultra-Low Emission and Visibility) plants. Cornerstones of this advanced concept are the mitigation of the visual impact of geothermal installations (well pads, pipelines and power stations), the abatement of pollutant emission and the use of low-exergy steam or waste heat for industrial activities and district heating.

The reduction of cooling water drift, an easier task, may be achieved by a state-of-the-art design for new plants and retrofitting the existing towers with an *ad hoc* improvement of drift eliminators, which is already being done.

Owing to the characteristics of Italian geothermal fluids, H_2S abatement technologies used elsewhere (particularly in California) are not readily applicable without modifications and/or may result in unacceptable operating costs. As an example, the use of surface condensers to achieve high H_2S partitioning to the gas phase would involve a significant penalty both in terms of investment costs and performance, due to the high NCG content of the steam. In addition, NCG direct combustion (required by the burner-scrubber process, suitable for plants equipped with direct-contact condensers) is prevented by the very low heat of combustion of the NCG.

Mercury abatement, on the other hand, is not yet a standard practice in the geothermal industry, being applied only to prevent sulfur contamination produced by downstream H_2S abatement at The Geysers (Grande, 1995), where the mercury content of the steam is considerably lower than at Piancastagnaio.

It was thus decided to make a survey of the commercially available abatement processes, in order to evaluate the possibility of applying them in ENEL's power plants (both new and existing) as well as their economic impact on the generation cost.

After an initial screening, the following hydrogen sulfide abatement processes were evaluated:

- Thermal conversion to sulfur dioxide (possibly followed by SO_2 abatement).
- Catalytic conversion to sulfur dioxide (possibly followed by SO_2 abatement).
- Selective catalytic oxidation to elemental sulfur (Superclaus and Sulfreen® processes).
- Liquid phase redox oxidation to elemental sulfur (LO-CAT II® and Stretford processes).
- Burner-scrubber or low-solids (RT-2) process.

Liquid phase oxidation to sulfates with less-than-stoichiometric amounts of reactant (BIOX process) was also investigated, but discarded following unsatisfactory laboratory test results (Nardini *et al.*, 1995), confirmed by a subsequent field test performed at Molinetto (8 MW) power plant (ENEL, 1996).

The possibility of achieving high H_2S partitioning to the gas phase by cooling water pH modification in power plants equipped with direct-contact condensers was investigated both with laboratory and field tests, the latter also carried out at Molinetto, where sulfuric acid was added (Nardini *et al.*, 1996; Baldacci *et al.*, 1996).

As far as mercury abatement is concerned, the following processes were evaluated, both as stand-alone and in combination with the H_2S abatement processes listed above:

- Condensation and separation by gas cooling and refrigeration.
- Absorption on sulfur impregnated activated carbon.
- Absorption on sulfur impregnated zeolites (Medisorbon process).

The choice of the best solution for H_2S abatement is also dependent on the SO_2 emission allowed. As the situation is subject to possible future restrictions, the selected technology should provide the possibility of meeting more stringent emission standards without incurring in unsustainable costs.

The scheme of the proposed abatement plant, as shown in Figure 4, provides for the following steps:

- Cooling of the compressor NCG discharge in a closed-loop direct-contact cooler (condensate from the moisture content of the NCG is discharged as blowdown), where the recirculating liquid is cooled by water from the cooling towers in a heat exchanger (direct surface cooling of the NCG is prevented by the fact that it contains a small amount of sulfur vapor produced by H_2S oxidation in the compressor).
- Mercury absorption with sulfur impregnated activated carbon.
- Regenerative heating of the NCG entering the catalytic reactor using the outlet gas.

- Catalytic conversion of hydrogen sulfide to sulfur dioxide (in the 200-400°C range).
- Gas quenching and sulfur dioxide absorption in a side stream of water from the cooling towers. Dissolved SO_2 drives the pH of the cooling water to acidic values, so that a high partitioning of H_2S to the gas phase can be achieved. In order to prevent extremely low pH values, the excess SO_2 bypasses the absorption stage.

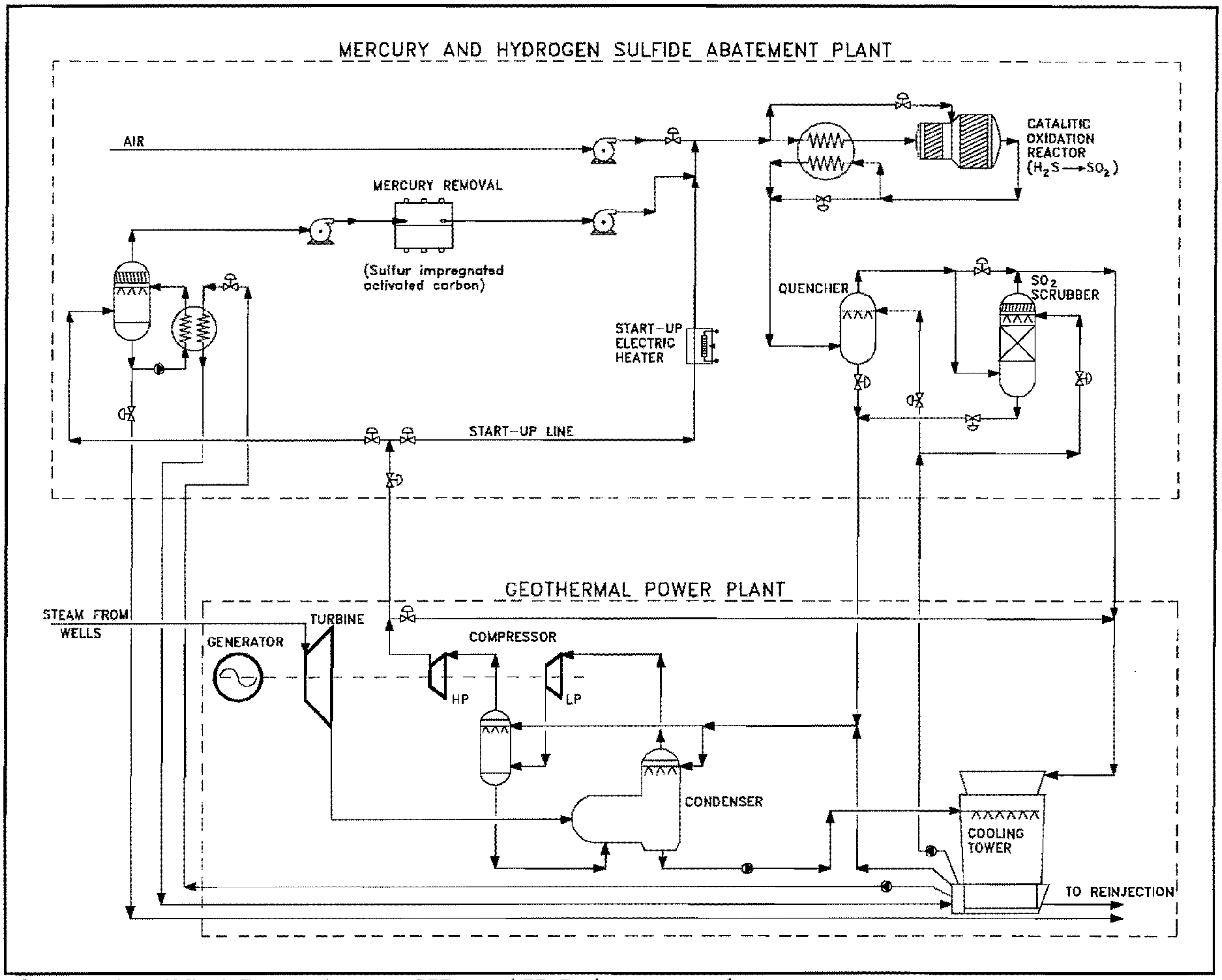

Fig. 4 Simplified flow scheme of Hg and H_2S abatement plant

Mercury abatement should be well over 90%, while H_2S residual emission (from stripping in the cooling towers) should be less than 10%. Around 50% of the SO_2 produced should be absorbed in the circulating water and eventually reinjected, thanks to the ammonia content of the steam (Dorrity, 1995), while the remaining part is released to the atmosphere.

However, the process can be easily implemented at a later stage with the addition of ammonia (or caustic), in order to abate 99%+ of SO_2 emissions. If required, residual H_2S could be abated, too, by adding iron chelates to the cooling water. These are both well-known technologies used in the RT-2 process (Bedell *et al.*, 1986; Dorrity, 1995).

Pilot-scale field tests of various oxidation catalysts will be carried out this year, with the aim of evaluating their optimum operating conditions and checking any poisonous effects of the trace elements present in the NCG on the catalysts. In addition, pilot testing of the activated carbon for mercury abatement is planned, in order to assess the absorption capacity and to check any possible side reaction, in particular H_2S oxidation to sulfur.

A full-scale abatement plant for a 20 MW power plant will then be designed, built and operated in order to gain some experience in the process before starting with the construction of additional plants.

CONCLUSIONS

Until recently, geothermal development has been pushed by technical and economic considerations only, with an increasingly prevailing weight of the latter in more recent years, following the ongoing privatization of ENEL.

Environmental conservation and socio-economic aspects have become qualifying issues of present and future activities, however, as no further development can be carried out without the acceptance of the local residents.

Thorough environmental studies have been conducted to assess the impact of existing or planned geothermal activities. When necessary, as in the Mt. Amiata area, the extent of these studies goes well beyond the requirements set by the current regulations.

Continuous monitoring of air quality has been completed or is under way in all geothermal fields under exploitation. Abatement of the main pollutants, particularly H_2S, in order to eliminate odor nuisance, and mercury, is close to the demonstration stage and will be subsequently applied to new power plants. The retrofit of a certain number of existing power plants is foreseen as well. Moreover, new plants and related pipelines will feature a reduced visual impact.

ENEL is confident that these measures will make possible the future development of all the resources available, within the constraints of the economic viability of geothermal power generation.

REFERENCES

Allegrini, G., Giordano, G., Moscatelli, G., Palamà, A., Pollastri, G.G. and Tosi, G.P. (1985). New Trends in Designing and Constructing Geothermal Power Plants in Italy, *Proceedings of the 1985 International Symposium on Geothermal Energy, Int'l. Volume*, pp. 279-288.

Allegrini, G., Cappetti, G. and Sabatelli, F. (1995). Geothermal Development in Italy: Country Update Report, *Proceedings of the World Geothermal Congress 1995*, pp. 201-208.

Baldacci, A., Culivicchi, G., Lenzi, A. and Sabatelli, F. (1996). Increased H_2S Partitioning by Acid Addition in a Power Plant Equipped With a Direct-Contact Condenser, *Geothermal Resources Council Trans.* **20**, pp. 3-10.

Bedell, S.A., Kirby, L.H. and Buenger, C.F. (1986). Chelation Chemistry for Geothermal H_2S Abatement, *Geothermal Resources Council Trans.* **10**, pp. 365-368.

Dorrity, C.M. (1995). Utilizing the Ammonia in Geothermal Steam for H_2S Abatement, *Geothermal Resources Council Trans.* **19**, pp. 439-443.

ENEL (1996). *Results of TCCA Tests at Molinetto Power Plant*, Internal Report.

Grande, M.G. (1995). The Economic and Environmentally Sound Handling of Geothermal Sulfur Byproducts: A Case History, *Geothermal Resources Council Trans.* **19**, pp. 445-450.

Nardini, G., Paglianti, A. and Petarca, L. (1995). An Analysis on the BIOX Process to Hydrogen Sulfide Abatement, *Geothermal Resources Council Trans.* **19**, pp. 457-461.

Nardini, G., Paglianti, A., Petarca, L. and Baldacci, A. (1996). A New Method to Solve the Problem of Hydrogen Sulfide Emission in Geothermal Power Plants, *Geothermal Resources Council Trans.* **20**, pp. 29-35.