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Geothermal Power Generation in the World 2015-2020 Update Report

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ABSTRACT

We have analyzed the major activities carried out for generation of geothermal electricity since WGC 2015. New data has been taken from the WGC 2020 Country Update reports, private communications from IGA members, and affiliated organizations. The author would like to acknowledge all of these data sources for their valuable help. Other updates have been collected from websites of private and public organizations involved in geothermal development as well as via personal communications. Plants under construction which are expected to be commissioned in 2020 are included in the installed capacity. An increase of about 3.649 GW has been achieved (about 27%) in the five year term 2015-2020. This figure deviates only slightly from the roughly linear increase trend documented since 2010. Five countries generated geothermal power for the first time. They are Belgium (0.8 MWe), Chile (48 MWe), Croatia (16.5 MWe), Honduras (35 MWe), and Hungary (3 MWe).

1. INTRODUCTION

Though the author has written similar reports for WGS meetings in the past, it will be a difficult task to follow the path of Rugerro Bertani who has written so many excellent recent WGC Rapporteur reports and who sadly passed away too soon.

In this, the WGC 2020 Rapporteur report, the major achievements of all nations having commissioned new geothermal power plants between 2015 and 2019 have been summarized. In all cases the information presented below has been abstracted from the official "Country Update" papers submitted to WGC, supplemented by internet information, and/or communications with knowledgeable persons. In addition, the status of geothermal power plant exploration and pre-construction activities has been documented for those nations, deemed by the author, to be close to joining the list of geothermal power generating countries.

For increased clarity, two tables and four figures have been included. Table 1 Lists the minimum figures for three important geothermal power generation parameters during the 2015-2020 period. Table 2 lists the nations now generating geothermal power and several considered to have the potential for coming on line in the relatively near term future.

Table 1: Selected World Geothermal Industry Statistics 2015-2020

Total Number of Wells drilled for power projects	1159
$US Millions spent on power projects	10,367
Number of Person-Years allocated to power projects	30,491

Figure 1 depicts the trends of the world's total installed capacity since 2010 while Figure 2 shows the percent change for each 5 year period. Note the modest decline in the predicted capacity increase forecast for 2025. This appears to be due to price-related competition from solar, wind, and natural gas, together with hesitancy on the parts of many national governments to foster new geothermal development.

Of note is the fact that the World Energy Council predicts that under three optimistic, basic, and pessimistic scenarios, has forecast that the geothermal compound annual growth rate over the period 2015 to 2060 will approximate only 5.4%, 4.6%, and 3.4% respectively. Even the optimistic case appears to be well below the 19.0% growth shown in Figure 2 for the 2020-2025 forecast. The latter rate may be over-optimistic, but it is based on plans and estimates documented by the authors of the Country Update papers.

Figure 3 shows graphically the number of megawatts electric (MWe) of installed capacity installed during the last 5 years by nations that already had commissioned one or more geothermal power plants prior to 2015. Figure 4 displays almost all of the geothermal power plants in service in 2020, in an earlier map from ThinkGeoEnergy. A few recently commissioned plants are not shown.

It is hoped that this document accurately describes the current status of the geothermal industry in those nations generating power. The number of installed MWe is the gross figure, but the Gigawatt-hours per year (GWh/yr.) figures are the product of the net power and the number of hours it was available to the national grid.

Please note that in Table 2, some GWh/yr. figures have been estimated because the actual number was not given by the author(s) in the text or tables of their relevant nations update paper. The estimate 2020 figure was calculated by determining the ratio of the 2020 MWe number to the previously documented 2015 MWe number and then applying that ratio to the 2015 GWh/yr. last documented by Bertani. Table 3 lists the ten nations generating the most geothermal electric power as of 2020.

Table 2: Geothermal power and energy generation statistics for 2015 through 2020

Country	Installed. MWe 2015	Energy GWh/yr. 2015	Installed MWe 2020	Energy GWh/yr. 2020	Forecast for 2025 MWe	MWe Increase since 2015
Argentina	0.00	0.00	0.00	0.00	30.00	0.00
Australia	1.10	0.50	0.62	1.70	0.31	-0.48
Austria	1.40	3.80	1.25	2.20	2.20	-0.15
Belgium	0.00	0.00	0.80	2.00	0.20	0.80
Chile	0.00	0.00	48.00	400.00	81.00	48.00
China	27.00	150.00	34.89	174.60	386.00	7.89
Costa Rica	207.00	1,511.00	262.00	1,559.00	262.00	55.00
Croatia	0.00	0.00	16.50	76.00	24.00	16.50
El Salvador	204.00	1,442.00	204.00	1,442.00	284.00	0.00
Ethiopia	7.30	10.00	7.30	58.00	31.30	0.00
France	16.00	115.00	17.00	136.00	~25	1.00
Germany	27.00	35.00	43.00	165.00	43.00	16.00
Guatemala	52.00	237.00	52.00	237.00	95.00	0.00
Honduras	0.00	0.00	35.00	297.00	35.00	35.00
Hungary	0.00	0.00	3.00	5.30	3.00	3.00
Iceland	665.00	5,245.00	755.00	6,010.00	755.00	90.00
Indonesia	1,340.00	9,600.00	2,289.00	15,315.00	4,362.00	949.00
Italy	916.00	5,660.00	916.00	6,100.00	936.00	0.00
Japan	519.00	2,687.00	550.00	2,409.00	554.00	31.00
Kenya	594.00	2,848.00	1,193.00	9,930.00	600.00	599.00
Mexico	1,017.00	6,071.00	1,005.80	5,375.00	1,061.00	-11.20
Nicaragua	159.00	492.00	159.00	492.00	159.00	0.00
N. Z.	1,005.00	7,000.00	1,064.00	7,728.00	200.00	59.00
P.N.G.	50.00	432.00	11.00	97.00	50.00	-39.00
Philippines	1,870.00	9,646.00	1,918.00	9,893.00	2,009.00	48.00
Portugal	29.00	196.00	33.00	216.00	43.00	4.00
Russia	82.00	441.00	82.00	441.00	96.00	0.00
Taiwan	0.10	1.00	0.30	2.60	162.00	0.20
Turkey	397.00	3,127.00	1,549.00	8,168.00	2,600.00	1,152.00
USA	3,098.00	16,600.00	3,700.00	18,366.00	4,313.00	602.00
Near Term Potential						
Dominica	0.00				7.00	
Montserrat	0.00				3.00	
Nevis	0.00				9.00	
St. Lucia	0.00				30.00	
St. Vincent	0.00				10.00	
Canada	0.00				10.00	
Greece	0.00				30.00	
Iran	0.00				5.00	
Ecuador	0.00				50.00	
TOTALS	12,283.90	73,550.30	15,950.46	95,098.40	19,331.01	3,666.56

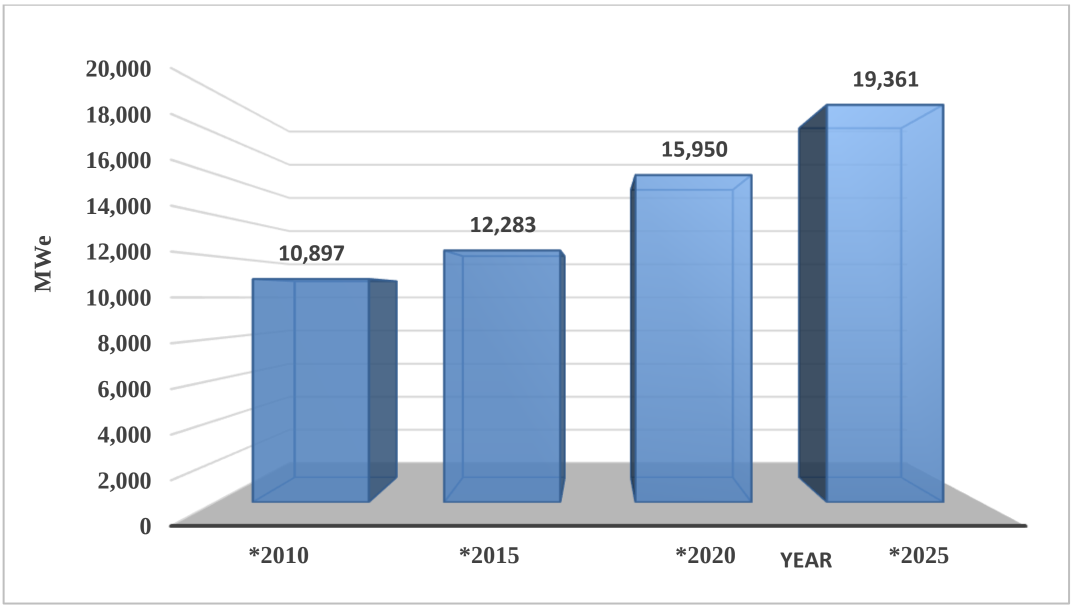

Figure 1: World Total Installed Capacity 2010 to 2025

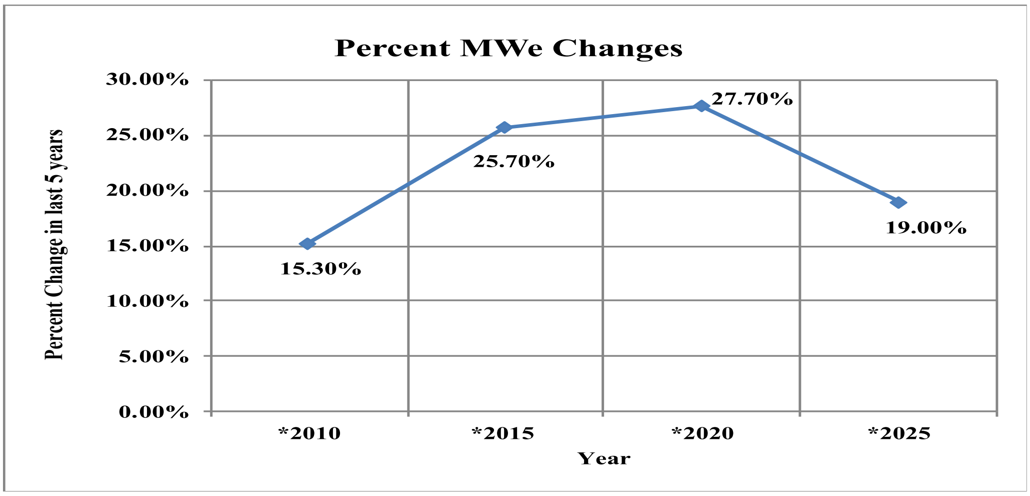

Figure 2: Percent Total Installed Capacity MWe changes from 2010 to 2025

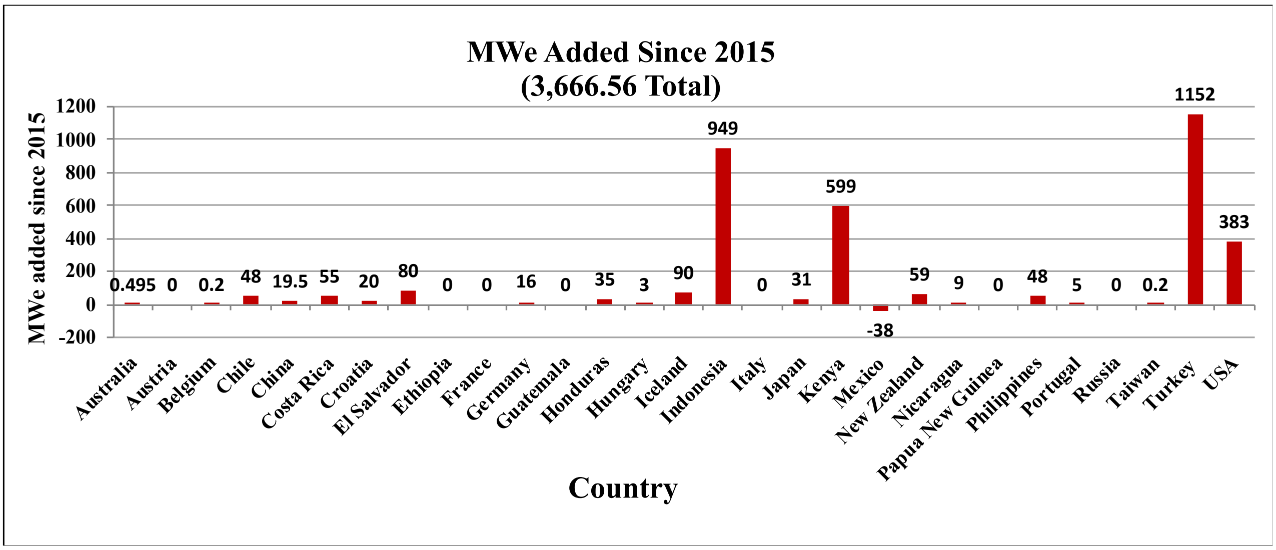

Figure 3: MWe added since 2015 by nations previously having installed power plants

Figure 4: Geothermal Power Plants (source ThinkGeoEnergy)

Table 3 – Ten nations having the most installed geothermal power generation in 2020

Country	MWe Installed in 2020		Country	MWe Installed in 2020
1. U.S.A	3,700		6. Mexico	1,105
2. Indonesia	2,289		7. New Zealand	1,064
3. Philippines	1,918		8. Italy	916
4. Turkey	1,549		9. Japan	550
5. Kenya	1,193		10. Iceland	755

2. GEOTHERMAL POWER GENERATION:

2.1 Argentina

Since 2015, there has been no geothermal power development despite a forecast for 30 MWe made in 2015. The most advanced prospect is at Copahue which is at the feasibility stage having been tested via three wells and the brief installation of a 0.67 MWe binary power plant that was then shut down in 1996. The Copahue resource is believed to be liquid-dominated, with a temperature of ~280ºC below a depth of ~1,500 meters, and the potential to generate 30 MWe for 30 years.

Other prospective sites for power generation include: Domuyo, Tuzgle, Tocomar, and Los Despoblados. Several sites believed to have significant potential are: Volcano Socomba, Cuenca Tucuman-Santiago del Estero, Caldera del Serro Blanca, Volcano Peteroa, and Laguna del Maule. The ultimate potential for geothermal power generation is reportedly ~1,000 MWe.

2.2 Australia

All geothermal power generation projects that existed before 2015 have been abandoned including the high profile EGS effort in the Cooper Basin. The nation's longest running geothermal plant, the 120 kWe installation at Birdsville was decommissioned in 2018 in favor of solar PV together with battery storage. The commissioning of a new 310 kWe generator at Winton was announced in October 2019 and tenders have been released for another small plant at Thargomindah. Both of these sites are off-grid in southwestern Queensland and are economically viable only because they will use binary plants operating on 80-90ºC waters taken from existing water wells.

It is possible that interest in geothermal power generation could see a revival if Federal and State policies shift towards a low emission, reliable, cost-effective fuel supply. Unfortunately, geothermal research funding has decreased resulting in fewer dedicated programs to study the challenges of direct-use or power generation.

The Australian Geothermal Energy Group (AGEG) and the Australian Geothermal Energy Association (AGEA) have both been de-registered and the Australian geothermal sector is now represented within the International Geothermal Association IGA) by the Australian Geothermal Association (AGA) created in 2016.

2.3 Austria

As of 2015, Austria had a single ORC geothermal power plant with generating 1.25 MWe gross and 2.2 GWh/yr. at Bad Blumau, near the Safen River, in Styria, which is in extreme southeastern Austria. As of 2019, there have been no new power plants commissioned, there are none under construction, and no new plants are forecast for 2020.

The single well fueling the Bad Blumau plant has a wellhead temperature of 110ºC and an outflow of 50ºC. The flow rate is 28.5 kg/sec. Only one other deep geothermal well, the Mehrnbach TH 3.1/1a, was drilled during the last 5 years. That well was 2,865 meters deep and bottomed in granitic basement rocks. The well was dry and was abandoned.

Unfortunately, the Austrian government's future energy policies, as currently expressed, do not include expansion of geothermal power generation.

2.3 Belgium

In 2016, two wells were drilled near Mol-Donk in northern Belgium to depths of 3,600 meters. The targeted geothermal reservoir was a fractured carboniferous formation. Bottom-hole temperatures in the wells were 138-142ºC, making them useable for district heating and for fueling a 0.8 MWe binary power plant that can supply the grid with 2 GWh/yr. of energy. It is possible that another 0.6 MWe could come on line by 2020. If so then the energy supplied would increase to ~2 GWh/y. Finally, efforts are beginning to study the EGS potential beneath Belgium. This would be a great addition to the installed geothermal capacity if successful.

In the 2015-2019 period, 123 person-years of time were spent on geothermal work by government, university, utility, and consultant staff. Another 1080 person-years were undertaken by private industry representatives.

Research and development expenditures were ~$US 8.5 million; field development and drilling costs were ~$US 30 million; and the utilization of electrical power cost $US 2 million, all during the 2015-2019 time frame. The private sector expended 80% of these funds while public money accounted for 20%.

Belgium is still focusing on achievement of their ambitious district heating goals, but considerable attention is also being given to determination of the potential for developing deep EGS resources for generation of more geothermal electricity in the near-term future.

2.4 Chile

In 2017, Chile began to develop its very large geothermal power generation potential by commissioning the 48 MWe, binary power plant at Cerro Pabellón, developed by Géotermica Del Norte, a joint venture between Enel Green Power and Empresa Nacional del Petróleo (ENAP). This same group plans to add another 33 MWe binary unit in late 2019.

In addition to Cerro Pabellón, there are two prospects that could be developed fairly soon, though not before 2020:

1) Mariposa, in Central Chile, which will be further explored by Energy Development Corporation (EDC) of the Philippines once it comes off its current stand-by status. Exploration results recorded there to date suggests the potential for generation of 160 MWe.

2) Peumayén (ex-Tolhuaca) located in Southern Chile. It is currently leased to Transmark of the Netherlands and has a potential initial capacity of 70 MWe. This project is located high on the volcano and will require long transmission lines to reach the grid.

In 2018, the Mesa de Geotermia (Geothermal Round Table) report was submitted by the Chilean Ministry of Energy. It was written in concert with developers, private industry, and academia, all supported by the World Bank. The main report conclusions are that ~599 MWe could be on line by 2030 and an additional ~1,487 MWe could be installed between 2030 and 2050.

Despite an enthusiastic government policy regarding further geothermal power development, the nation's vast potential is unlikely to be utilized unless and until economic barriers (primarily the very low electricity prices) are addressed.

2.5 China

China has seen fairly rapid geothermal development in the past five year, with most of it in the direct use sector. With regard to geothermal electric power generation, the 16 MWe Yangyi project in Tibet came on line, a test unit of 400 kWe was built at Kangding in Sichuan province, and a 2 MWe plant was built at Dehong in Yunnan province. Accordingly, the 2019 installed capacity is 34.89 MWe (including the 25.2 MWe plants at Yangbajing, Tibet).

China predicts that by 2020, they will be generating 386.68 MWe plus any EGS power that might result from on-going exploration. New prospects include Ganzi (200 MWe), Dehong (100 MWe), and Boye, Hebei, and Gaoyang (each 15 MWe). EGS drilling has also begun in the Gonghe Basin of Gansu Province.

The Chinese government is enthusiastically promoting the use of geothermal resource for direct use purposes and is undertaking large, successful heat pump installations. Accordingly, the nation is becoming one of the geothermally most active in the world.

2.6 Costa Rica

Geothermally-fueled electric power has been generated in Costa Rica since 1994 when the first of five units was built at the Miravalles field (now called the Alfredo Mainieri Protti field). The last of these expansions was completed in 2003 for a total installed capacity of 161 MWe. In 2011, the first of three planned units was completed at Las Pailas. It was a hybrid, binary and single flash, system that had an installed capacity of 42.5 MWE. A second 55 MWe Las Pailas plant was commissioned in July

2019. Presently the total installed geothermal capacity is 207 MWe with 969 GWh/y of energy contributed to the grid. There are 55 MWe under construction and another 110 MWe funded but not yet begun. By 2025, Costa Rica plans to have a capacity of 262 MWe installed and be putting 1,559 GWh/y into the grid.

Miravalles has apparently reached the limits of its power potential and the main aquifer is declining in temperature and pressure. Efforts to mitigate this include drilling deeper so as to intersect a suspected hotter zone, exploration southeast of the main field to seek additional viable part of the resource, improvement of all the non-condensable gas extraction systems so as to get more power out of existing installations, and efficiency improvements of the entire reinjection system.

Las Pailas is also near the geographically useable limit of its field as it is adjacent to a National Park that is currently off limits to geothermal exploration and/or drilling. The lifting of such restrictions has been, and continues to be, a contentious topic debated by environmentalists and pro-renewable energy groups in Congress.

Borinquen is a field in which 20 wells have been drilled with excellent results. Accordingly, the construction of the first of two 55 MWe plants has been scheduled for 2026 at which time it will replace existing, ageing thermal plant(s). There are several more prospective geothermal sites in Costa Rica. They include Poco Sol, Tenorio, Caño Negro, Liberia San Jorge, Tilarån, Puerto Viejo, San José, and La Tigra. Exploration of these sites is in different stages, but some or all of these fields could, reportedly, be active by 2060.

2.7 Croatia

Near the end of 2018, the first Croatian geothermal power plant, Velika 1, began operation at the Velika Ciglena site located in Bjelovar, in the northeastern part of the nation. This was an important achievement for the national geothermal sector, as the site has been investigated since the 1980s.

At the Velika 1 facility, there are two production/injection doublets and a 16.5 MW turbine that delivers ~10 MW (net) and 76 GWh/yr. to the power grid. The power is generated using a Turboden ORC system operating on 170^{o}C thermal waters.

In September 2019, an announcement was made to the effect that a 19.9 MWe binary power plant would be built in Legrad, close to the city of Koprivnica, in the northern part of Croatia. The facility is anticipated to provide ~ 165 GWh/yr. of energy.

Another ongoing project is a hybrid geothermal power scenario at Kotoriba, northwestern Croatia where resource temperatures of 192^{o}C have been recorded. The project will include an ORC power plant, together with the use of methane dissolved in the geothermal water for four cogeneration units. These will use the heat from exhaust gases, separate any CO_2, and inject it, along with geothermal water outflow, back into to the reservoir. This project has national support, but no time-line for its construction has been announced.

Finally, there are reportedly another 4 MWe of geothermal power currently under construction at Kutnjak-Lunjkovec and Slatina in the northwest and the north-central regions so that by 2020, Croatia could be generating about 20 MWe and delivering about 100 GWh/yr. to the nation's electric system. In the period 2015-2019, about $US 7 million was invested in geothermal power projects, all of by the private sector.

2.8 El Salvador

In the absence of a Country Update paper from El Salvador for 2015-2020, the following text has been slightly modified and expanded from Bertani, 2015.

In El Salvador, geothermal resources have been one of the significant sources of electricity since the mid-1970s and as of 2015, the total installed capacity from geothermal resources was 204 MWe (Ahuachapan 95 MWe, Berlin 109 MWe). This met about 24% of power demand and provided 13% of the nations installed capacity. Energy provided to the grid was 1,442 GWh/yr..The development plans of LaGeo for 2015-2020 include a 28 MWe Unit 5 plus an 8 MWe second bottoming cycle at Berlin and 5 MWe for the re-powering of Unit 2 at the Auachapan field.

LaGeo continues to develop geothermal projects in the areas of Chinameca and San Vicente, where exploratory drilling has confirmed the existence of high enthalpy resources. Accordingly, 50 MWe and 30 MWe power plants are intended to be constructed at these two sites, respectively.

2.9 Ethiopia

Ethiopia is located on the geothermally active East African Rift zone and therefore has an abundance of sites that are prospective for generation of power. Twenty four such locations are claimed as is a potential for ultimate generation of 10,000 MWe. The current installed capacity is 7.3 MWe derived from the Aluto Langano field. It is located in the southern part of the rift, and as of 2015, exploration of an eastern extension was underway with hopes to generate another 30 MWe. It might be possible that an additional 24 MWe may come on line by 2025. A specific site was not mentioned.

A new geothermal law and associated regulations were put into effect in 2016. Ambitious plans publicized following this event were to generate 5,000 MWe by 2037. Reportedly, the government, the national utility (EEP), and the private sector are all actively exploring prospective areas so that, at least, "hundreds" of MWe could come on line in the next 5 years.

The prospects most advanced include Tendaho and its associated Alalobad area, Shalla Abiata, Butajira, Meteka, Corbetti, and Tulu Moye. Exploration at several of these has recorded temperatures greater than 200^{o}C. Permeability sufficiency has not been mentioned. In October 2019, a contract was signed to begin drilling at Tulu Moye. Plans are to build two plants of 50 MWe and 100 MWe respectively. No date was given for completion of the first phase, but it will likely be between 2020 and 2025.

2.10 France

France has not increased its geothermal power generation in the past 5 years. The only French installation is at La Bouillante located on the island of Guadeloupe in the Eastern Caribbean. The plant, generating 15 MWe gross and 10 MWe net, was built in two phases that were completed in 1996 and in 2011. In 2016, La Bouillante was sold by BRGM to Ormat. Permits for the drilling of two new wells have been granted and it expected that generation will increase to ~25 MWe by 2022.

On the French mainland, near Strasbourg, two doublets have been drilled to depths of 3,500 and 5,000 meters. The plan is to co-generate 10 MWe with 20 MWth of district heating. Finally, geoscientific surface exploration is being undertaken on the French islands of Martinique and La Réunion with the hopes of eventually generating power.

In 2015, the organization called GEODEEP was founded. Its membership includes large companies with expertise in research and development, project development, power plant equipment, operation and maintenance, engineering, as well as ESCOs and the Geothermal French association of professionals. The GEODEEP SAS fund will be operational in 2019, pending approval by the European Union. Its primary objective will be mitigation of the risks inherent in geothermal exploration on the French mainland as perceived by investors, developers, and insurers.

2.11 Germany

Geothermal power in Germany comprises 10 plants using Kalina or ORC systems thus allowing applications of only 100°C. Installed capacity is now 43.05 MWe with a total power output of 165.6 GWh/yr.

Since the last country update in 2015 four new geothermal power plants were commissioned in Germany: the 4.3 MWe plant in Grünwald/Laufzorn (October 2014), the 5.5 MWe plant in Traunreut (2016), the 4.3 MWe plant in Taufkirchen (2018), and the 3.6 MWe plant in Holzkirchen (2019) (all located in the South German Molasse Basin). However, the 3.36 MWe geothermal plant in Unterhaching was shut down end of 2017. Therefore, the installed geothermal capacity in Germany showed only small growth. In October 2019, it was announced that a 4.3 MWe binary plant will be built at Garching, northeast of Munich. Commissioning is expected to be in the autumn of 2020.

Germany has been very actively expanding its district heating, industrial, and heat pump project deployments. The federal government is quite supportive and has instituted several incentives including feed-in tariffs and tax benefits for investors. Accordingly, power may be co-generated when planned wells are drilled into the several known “deep” reservoirs so as to tap resources amenable to binary cycle use. If and when EGS becomes commercially viable, Germany may have suitable Permian age target formations that could be tested.

2.12 Guatemala

Though the estimated geothermal potential of Guatemala may be ~1,000 MWe, to date there are only two power plants on line and Ormat operates them both, with installed capacities of 28 MWe gross at Zunil and 24 MWe gross at Ortitlan. Combined, in 2018, the two contributed 39.28 MWe and 237 GWh/yr. net to the grid or ~1.14% of the nation’s energy matrix.

There are three projects currently under development by mining companies: Cerro Blanco – 50 MWe at Juniapa, El Ceibillo – 25 MWe at Guatemala, and El Porvenir – 20 MWe at Zacapa. At the end of 2018, El Ceibillo was purchased by Ormat; however no date for operation has yet been publicized.

There have been no new projects brought on line in Guatemala since 2015. The growing political and social crises in the country have discouraged new private investors despite passage of several laws designed to incentivize private sector participation in more geothermal development.

2.13 Honduras

In September of 2017, the first geothermal power plant in Honduras was commissioned at Platanares. The installed capacity is 35 MWe and it is generating ~25 MWe net. Ormat is managing the project according to terms of a Build-Operate-Transfer (BOT) contract with the National Electric Company. The field contributed 15,000 to 25,000 MWh monthly to the grid in 2017, and 18,000 to 27,000 MWh monthly in 2018 and to date in 2019. Platanares is now transmitting about 297 GWh of power.

In the 1980s, several other prospective high temperature areas were identified and geothermometric temperatures were recorded: Platanares (225°C), San Ignacio (190°C), Azacualpa (185°C), Pavana (170°C), and Sambo Creek (155°C). More recently studies under the aegis of the National Electric Company has found promising sites at El Olivar (170°C), Namasigue (185°C), and La Barca (85°C).

The government of Honduras has passed several Laws, Rules, and Regulations intended to make further geothermal development economically viable. Progress has been slow, but there is hope that the pace will accelerate in the next decade.

2.14 Hungary

The first geothermal power plant in Hungary was commissioned in 2018 at Tura. The installed capacity is 3.0 MWe, but output currently is 2.3 MWe and with parasitic losses, only 1.3 MWe is transmitted to the grid. The resource temperature is 125°C and production is from a depth of 1,500 meters. Two injection wells receive the underflow of about 6,000 l/min. There is excellent geothermal potential in Paleozoic through Mesozoic rocks in southeastern Hungary. This area could be developed by traditional binary and even by some single flash power plants. At greater depths in this region, there may well be EGS potential as temperatures well over 200°C have been recorded in petroleum wells.

Future electrical power geothermal development in Hungary will be dependent on the adoption of appropriate national energy policies that are supported by legal and financial conditions that attract capital investment from the risk-averse private sector. These barriers are being addressed and optimistically, there could be one or more Hungarian power projects developed before 2025.

2.15 Iceland

Since 1969, Iceland has gradually increased its usage of geothermal energy for district heating, for agriculture, aquaculture, light industrial purposes, numerous other direct uses, and for power generation. Accordingly, geothermal energy currently supplies 62% of the country's energy production. The installed capacity of the electric power segment now totals 663 MWe (5,245 GWh/yr) and by 2020, it is forecast to be 755 MWe (~6,010 GWh/yr.) generated at eight sites, all along the three NE-SW trending volcanic ranges that transect the country. The currently operating plant names and their installed capacities are: Krafla (60 MWe), Svartsengi (76.4 MWe), Bjarnflag (5.0 MWe), Nesjavellir (120 MWe), Reykjanes (100 MWe), Hellisheidi (303 MWe) and Theistareykir (90 MWe), and Fludir (0.6 MWe)..

Of special relevance to the time period addressed in WGC 2020 is the Theistareykir power plant that was built in 2016 and 2017. The power is generated by two 45 MWe single-flash units. The resource temperature is ~178^{o}C and the flow rate is ~ 560 T/hr. so that 738 GWh/yr. can be transmitted to the grid.

With regard to future geothermal expansion, Iceland has contracted to purchase several new Swedish-built Climeon binary cycle machines that can operate using low temperature (<150^{o}C) resources. The machines generate about 150 kW and will be installed at several sites. The first of these was built at Flúdir where 116^{o}C water is now being used to generate 0.6 MWe, with the underflow cascaded at 76^{o}C to a district heating project.

As testimony to the ongoing interest in expansion of geothermal use, 4 to 8 high temperature wells are being drilled annually. Of special interest was the drilling of the deep well at Reykjanes as part of the Iceland Deep Drilling Project (IDDP). The well was spudded in August 2016 and completed in January 2017. Temperatures above 500^{o}C were recorded together with some permeability between depths of 3 to 4 km. The well has not yet been production tested.

Before and during the period 2015-2019, the Icelandic government and several Iceland-based private sector companies have been actively promoting geothermal business within the nation and world-wide. Icelandic consulting and drilling firms are playing key roles in projects within developing countries on all continents except those in the Arctic and Antarctic.

2.16 Indonesia

Indonesia has the largest geothermal potential in the world with an estimated 29 GWe anticipated to come from more than 300 sites. From 2015 through 2018, three new projects came on line increasing total installed capacity by 465 MWe to 1,948.5 MWe. In addition, the following capacity increases were completed: In 2016: Lahendong – 40 MWe, Ulubelu – 55 MWe, and Sarulla – 110 MWe. In 2017: Ulubelu – 55 MWe and Sarulla – 110 MWe and in 2018: Karaha – 30 MWe and Sarulla – 110 MWe. By the end of 2018, 14.01 GWh/yr were being generated.

In 2019, it is expected that the following new power plants will be commissioned: Lumut Balai – 55 MWe, Sorik Merapi Units 1 and 2 – 20 and 30 MWe respectively, Sokoria Unit 1 – 5 MWe, and Muara Laboh Unit 1 – 80 MWe for an additional total of 190 MWe. Therefore, by December 2019, the total installed capacity could be 2,138.5 MWe. Towards this end, 187 wells were drilled at 23 discrete sites between 2015 and 2018.

Despite efforts by the Government of Indonesia (GoI) to accelerate geothermal development, ambitious installed capacity targets set in 2015 have not been met and growth in project development has actually slowed since 2017. The GoI target for installed capacity by 2020 is now 2,289 MWe and for 2025 it is 7,000 MWe, but unattractive rates of return, high perceived risks related to Power Purchase Agreements, and significant environmental and social problems make achievement of this figure unlikely.

2.17 Italy

Geothermal power generation began in Lardarello in 1904. As of 2018, there are 37 generating plants located in the three main fields of Lardarello, Monte Amiata, and Travali-Radicondoli. Total installed capacity is 915.5 MWe, net generation is 807 MWe using more than 500 wells, and gross power output to the grid is 6,105 GWh/yr. Geothermal comprises only 2.1% of the national power needs, but supplies more than 30% of the electricity needed by the Province of Tuscany.

Drilling in the period 2015 to 2019 has comprised 28 wells including 14 make-up wells, 2 new reinjection wells, and 16 workover wells all within the Lardarello and Travale-Radicondoli areas. There have been no new power-plants built since 2015, but $US 263 million were spent on development, work-overs, and field improvements, especially with regard to the abatement of non-condensable gasses. All of these funds were expended by the private sector.

The only new project under construction is the 20 MWe Monterotondo 2 plant. Surface exploration was successfully completed in 2018 and preliminary drilling is underway as of August 2019. This plant could be on line by 2020. Otherwise, the forecast for growth of all Renewable Energy Sources (RES) is low, primarily because of low prices being paid for power and significant reductions in so-called "Base Incentive Fees". In addition, geothermal power plants are not eligible to receive incentives available to other RES plants.

The activities carried out by Enel Green Power (EGP) since 2015 have been concentrated mainly in the Larderello and Travale-Radicondoli areas and are focused on field management optimization so as to reduce and control the natural power output decline. Serious objections by residents of local communities have hindered further developments in the Mt. Amiata area, where the high potential deep reservoir could otherwise be further exploited.

2.18 Japan

Little geothermal development was undertaken in Japan between 2000 and 2012. In the latter year, a Feed-in-Tariff was implemented, and the rate of construction of generating units increased dramatically so that by 2018 there were 69 units as compared to 20 units in the year 2000. Most of these newer plants were quite small, ranging from 100 kWe to about 5 MWe and averaging about 500 kWe. Accordingly, the aggregate capacity increase was only 24.4 MWe. Because several units were quite old and inefficient, they were decommissioned and output decreased by 68.2 MWe. Then, in 2019, construction of two larger power plants began at Wasabizawa (46.2 MWe) and Matsuo-Hachimantai (7.5 MWe) so as to boost capacity by 53.7 MWe. By 2020, it is expected that the total Japanese installed capacity will be 550 MWe, the gross production will be 2,409 GWh/yr and the net power output will approximate 275 MWe.

The three primary reasons for the relatively slow rate of increase in geothermal development are: 1) the regulations limiting geothermal development in National Parks, 2) the high risks and costs associated with geothermal projects, and 3) a general "not-in-my-backyard" attitude among citizens living near thermal features and a fear that their onsens (geothermal baths) will be negatively affected by drilling and power plant operations. The government of Japan is aware of these barriers and is slowly attempting to overcome them in order to make more beneficial use of the nation's excellent geothermal potential.

2.19 Kenya

Kenya's geothermal capacity growth during the period 2015 to 2019 has been one of the fastest in the world. Installations have totaled 218 MWe, coming from the Orpower4 (45 MWe) and the Olkaria V (173.2 MWe) stations. Current total installed capacity is 865 MWe which comprises 29% of the national capacity. So far, more than 380 wells have been drilled in the several parts of the rift zones. The Government of Kenya (GoK) plans to have 5,000 MWe on line by 2030 and because financing through the national treasury is now scarce, the GoK has licensed 13 Independent Power Producers (IPPs) to explore 12 greenfield sites and requiring them to drill within three years after receipt of these licenses.

All except two of Kenya's geothermal developments have been accomplished using public financing. The remaining two have been privately funded using equity and bank loans. In order to improve the rates of return to both the public and private sectors, the use of wellhead generators has become common. To date, 15 of these small units have been installed and the initial revenue timing has thereby been reduced from about 36 months to about six months.

Recent rapid growth of geothermal power in Kenya has been facilitated by progressive government policies that support private investment. Terms of the New Energy Act of 2019 clarified the electricity market in terms of environmental safeguards, community and county profit shares of geothermal generation, dispatch preference, and it increased the fiscal incentives available to developers. Such incentives include duty waiver on geothermal project related equipment, corporate tax holidays, and letters of support from the GoK which act as a political guarantee. Private investors are also allowed to repatriate all or parts of profits made from the venture.

In addition to the 865 MWe of 2019 capacity, 188 MWe is under construction and 140 MWe has been funded but is not yet under construction. Therefore, by 2020, it may be possible that Kenya could have a total installed capacity of 1,193 MWe with a gross production of 9,930 GWh/yr.

2.20 Mexico

The total 2019 installed capacity from the five geothermal fields in Mexico is 1,005.8 MWe. The net power available to the grid from all five projects is 947.8 MWe (5,375 GWh/yr.). The installed capacity has decreased by 1.1% from that reported in 2015, but the net to grid has increased by 13% due to greater efficiencies in some newer units.

Geothermal electric power has been generated since 1982 when the first units at Cerro Prieto and Los Azufres were installed. Though Cerro Prieto field had 720 MWe at its maximum, it now has an installed capacity of 570 MWe. The Los Azufres field has 270.5 MWe installed. Los Humeros, that came on line in 1990, generates 119.8 MWe, Las Tres Virgenes (built in 2002) can put out 10 MWe and the new (2015) Domo de San Pedro field has a capacity of 35.5 MWe.

Despite the increased power delivered to the grid since 2015, the annual capacity factors at all five fields are fairly low though they vary from one field to another. For example, in 2018 the nine power plants operating in Cerro Prieto produced 3,251.2 GWh, which equates to a 65.1% annual average capacity factor. However, with 1,441.1 GWh generated in the same year, the eight plants in operation at Los Azufres achieved a capacity factor of 74.8%, which was the highest in the country. The lowest capacity factor was at the Las Tres Vírgenes field, with an annual average of only 54.3%. The newest field, Domo de San Pedro, developed by the Dragon Group, had a capacity factor of 56.7% while contributing 126.6 GWh/yr. to the grid.

In the last five years, the following five power plants came on line: 2015 - Los Azufres Unit 17 – 50 MWe , 2015 – Domo de San Pedro Unit 1 – 5 MWe (backpressure), 2015 – Domo de San Pedro Unit 2 – 5 MWe (backpressure), 2016 – Domo de San Pedro Unit 3 – 25.5 MWe, 2019 - Los Azufres Unit 18 – 26.5 MWe so that a total of 112 MWe was added in the period 2015-2019..

Since 2015, Comisión Federal de Electricidad (CFE) has been awarded thirteen prospective areas to explore and develop. Private sector companies have also received thirteen other concessions. If progress is made at some or all of these sites, the Ministry of Energy forecasts (optimistically) that 1,670 MWe could be generated geothermally by 2030.

For the period 2015-2019, nation-wide, an estimated US$55.9 million has been spent for research and development, including exploration drilling, and US$313.3 million for field construction. These figures total US$369.2 million, for an average annual investment of US$73.8 million. The results are 11.8% higher than the amount estimated for the previous five year period. Of special note is the increase in private sector investments that represented more than 22% of the total or around US$82.44 million.

This is more than four times greater than the private sector investment estimated in the period 2010-2104, when it was approximately US$16.5 million.

2.21 New Zealand

New Zealand has seen a period of consolidation in the geothermal electricity sector since 2015 following a period of rapid growth in the prior 10 years. Two power plants have been recently commissioned or are being constructed. At Kawerau the 25 MWe Te Ahi O Maui plant was put on line in September 2018 and at Ngāwha a 31.5 MWe plant is in the early construction phase. There is in New Zealand, more than 1,032 MWe (7,474 GWh/yr) of installed geothermal electricity generation capacity which typically contributes about 18% of the national electricity in a system increasingly dominated by renewable generation.

There are 129 identified geothermal areas throughout New Zealand, with fourteen in the 70-140ºC temperature range, seven in the 140-220ºC range and fifteen in the >220ºC range. Most high temperature systems are located in the Taupō Volcanic Zone (TVZ), which extends from Whakaari/White Island in the Bay of Plenty southwest to Mt Ruapehu.

In the last 5 years, only 7 wells have been drilled for electric generation purposes: 3 production wells and 4 injection wells. There is 31.5 MWe under construction so that by 2020, the total installed capacity should reach ~1,064 MWe supplying about 7,728 GWh/yr of energy to the national grid.

The New Zealand Ministry of Foreign Affairs and Trade (MFAT) administers an Overseas Development Assistance program, and has used New Zealand geothermal expertise to support partner governments. Over the last five years, MFAT has provided support to Indonesia, East Africa, the Caribbean, principally on St Vincent and Dominica, and on Vanuatu.

It is important to note that almost all of New Zealand's geothermal development has been undertaken by private or quasi-governmental entities, a scenario quite different from that played out in most of the other 25+ nations now generating geothermal power. The government of New Zealand played an important financial role in the International Geothermal School in its early years; however, as in the cases of Pisa, Italy and Reno, Nevada, USA, such support was eventually withdrawn so that other sources of funding have been necessary.

2.22 Nicaragua

In Nicaragua geothermal studies started in the 60's, and an impressive geothermal potential of the country has been estimated At about 1,100 MWe, but only a minimal part have been exploited to date, covering approximately 10% of the national electricity consumption. There are five geothermal areas, but there are power plants at only two of them (Momotombo, 77 MWe and San Jacinto-Tizate, 82 MWe). Development since WGC 2010 includes the 2x36 MWe units at San Jacinto-Tizate. (Bertani, 2015). Total installed capacity is 159 MWe and the energy provided to the grid is 492 GWh/yr..

Further exploration of the Casita-San Cristobal area in the north (4 wells drilled) and Masaya, Apoya, Managua Chiltepe (3 wells drilled), and Mombacho in the central part of the nation has been undertaken by the Nicaragua geologic survey and Icelandic investigators with promising results, however progress on the development of these prospects has been postponed by renewed political problems. Accordingly, World Bank funding, previously planned, has been delayed until resolution of this situation.

2.23 Papua New Guinea

There are 55 known geothermal sites in Papua New Guinea (PNG) that have been identified and recorded. To date, only one site, on Lihir Island, has been developed. Mapping, hot spring sampling, and geochemical analyses were undertaken in seven regions and the following prospective sites identified: Talasea, Hoskins, Wau Bulolo and Kairiru, Manus, Fergusson and the Feni Islands. These sites have been surveyed, to varying degrees, by private entities and/or the Mineral Resources Authority (MRA), a federal governmental agency. In 2003, a 6 MWe (gross) back-pressure power plant was constructed on Lihir Island. The plant was built in the extremely hot Luise volcanic caldera that was already being mined for its epithermal gold content. In 2005, a 30 MWe flash plant was added, followed in 2007 by a 20 MWe expansion. In 2009, the 6 MWe plant was decommissioned so that the current installed capacity is 50 MWe (gross). However, due to well-head pressure decreases caused by failure to reinject spent brines, the plant is now generating ~15-18 MWe and provides only 15% of Lihir's increased power requirement In the early years, the geothermal power produced 50% of the power requirement of the mine and greatly improved its economics. Despite the power losses cited above and associated salt water incursions, the mine is still being operated by Newcrest Mining Limited of Australia.

Though investigators have calculated that the total geothermal power potential in PNG may be 3-4,000 MWe, there have been no announced government plans to develop more geothermal during the next 5 to 10 years. On a more encouraging note, passage of the National Energy Policy of 2017-2027 should be a positive step, as its terms include directives to timely write geothermal policies, rules, and regulations. The existence of such documents should encourage geothermal investment from the government, international lending institutions, and the private sector. Funding for increased geothermal progress has largely been by the World Bank and the government of Iceland.

Other barriers to geothermal development that will need to be overcome, on a case by case basis, include rugged topography, few power users (except for mining ventures) among the predominantly rural population, communication with ~700 largely illiterate tribes using 800 different languages, societal and spiritual problems pertaining to land-ownership and associated matriarchal lineage customs, very limited road and transmission/distribution systems, and difficult access to some of the most prospective volcanic sites.

2.24 Philippines

Though the Philippines are the third largest producers of geothermal power, (after the USA and Indonesia), during the last 5 years, in April 2018, only a single 12 MWe power plant was commissioned at Maibarara Unit 2.

There are currently 7 operating geothermal fields in the nation. They have a total installed capacity of 1,918 MWe and provide 1,770 GWh/yr of energy to the grid. This comprises about 11% of the national electricity requirements. There are 18 prospective sites in the exploration stages and the addition of ~91 MWe is anticipated during the period 2021-2026. It has been estimated that the development potential of the Philippine geothermal resources will approximate 4,024 MWe.

If the pace of Philippine geothermal power plant commissioning is to increase, it will be necessary to synthesize and harmonize relevant government policies so as to address risks and other development challenges perceived by investors. The ongoing government-supported site evaluations and preliminary exploration work are important, but further appropriate financial and regulatory policies are still required.

2.25 Portugal

The only high temperature geothermal resources exploited to date in Portugal are located in the Azores archipelago located along a triple junction of plates within the Atlantic Ocean. The geothermal fields were first developed in 1980 at the Ribiera Grande and Pico Vermelho sites on San Miguel Island and then expanded to include Pico Alto field on Terciera Island where in April of 2017, a 4.0 MWe (gross), 3.0 MWe (net) ORC plant was commissioned. The latter is the only new power plant built within the 2015-2019 period.

Current plans are to increase the output of the Ribiera Grande plant from 27.8 MWe to about 30 MWe in the early 2020 decade. This would bring energy provision to about 183 GWh/yr.

Data provided show that current total installed capacity in the Azores is 33 MWe with a running capacity of 26 MWe. Energy produced is 216 GWh/yr. Funds for 10 MWe more have been allocated but construction has not yet begun. Total investment in electrical generation and utilization since 2015 was $US 12.5 million; half of which was from public coffers and half from private sector funds. Approximately 185 man-years of effort were expended during this period but there were no new wells drilled.

2.26 Russia

Russia has been exploring and developing its geothermal resources since the 1950s. The current installed capacity is about 82 MWe, with near term additions of about 12 MWe planned. Energy to the grid is estimated to be ~440 GWh/yr. Because no new geothermal power plants were built during the period 2015 to 2019, neither the power nor the energy contributions from geothermal have changed.

The largest and highest quality geothermal resources in Russia are in the far eastern part of the country. Specifically, Kamchatka and the Kuril Islands have the greatest potential, with an estimated generating power capacity of up to 2000 MWe. Since the middle of the 1950's geophysical surveys and drilling have been undertaken in the Kamchatka geothermal fields. To date 385 wells have been drilled to depths ranging from 170 to 1800 meters including 44 wells that produce two-phase fluids at a wellhead temperatures exceeding 160°C. In 1966, the Pauzhetskaya geothermal power plant was commissioned in the southern part of Kamchatka. Currently, it is successfully operating and generates the lowest cost electricity in the region. The estimated potential of this geothermal field is about 50 MWe for up to 30 years.

Currently, in Kamchatka, three geothermal power plants are successfully operating: 12 MWe and 50 MWe from the Verkhne - Mutnovsky and Mutnovsky fields respectively and 11 MWe from the Pauzhetsky field. On the Kuril Islands (Kunashir and Iturup) there are two small geothermal power plants each with a capacity of 3.6 MWe. Planned for the near term future are construction of a Pauzhetsky binary power plant of ~2.5 MWe capacity and extension of the existing Mutnovsky power plant so as to generate an additional ~12 MWe.

Russia possesses enormous reserves of geothermal heat, the energy from which has the potential to be 8-12 times greater than the potential from all their hydrocarbon fuels. If developed optimally, these geothermal resources could radically change the energy balance of the country.

2.27 Taiwan

Taiwan has studied its geothermal resources since the 1970s, leading to the construction of two small power plants in the 1980s. One at Cingshuei (3 MWe) was built in 1981 and retired in 1993, while the second, at Toucheng (0.26 MWe) was built in 1985 and retired in 1994. The reasons given for the retirements included a lack of reinjection, scaling, unsuitable machines, and the small scale of the projects, excessive operating costs, high drilling risks, and limited understanding of the underground geological reservoirs.

In 2019, a new 0.3 MWe plant with an energy output of 0.256 GWh/yr. was built at the Cingshuei site. An expansion of 4.2 MWe has been funded and is currently under construction. Accordingly, Taiwan's anticipated 2020 installed capacity will be 4.5 MWe and its energy contribution to the grid will be about 0.35 GWh/yr.

Twelve (12) more megawatts are currently planned for construction at three sites in 2021-2022 and construction of plants aggregating 150 MWe, from 5 sites, have been funded, but are not yet under construction. The latter include: New Taipei City (100 MWe), Ilan County (29 MWe), Hualien County (3 MWe), Taitung County (15 MWe), and Nantoo County (3 MWe).

From 2014 through 2019, Taiwan spent about $US 12.5 million on research plus field development. The field work included the drilling of 6 wells, all intended to confirm the existence of electric power-quality resources. The public contribution ranged from 75 to 100% for this work. The remainder was funded by the private sector.

Presently, the price paid by the Taiwanese consumer for electricity is about $US 0.08/kWh. The government has authorized a Feed-in Tariff of $US 0.16/kWh as an incentive to build new geothermal power capacity. It remains to be seen if this is enough to motivate national and/or international investors.

2.28 Turkey

Since geothermal exploration began in Turkey during the 1960s, 460 prospective fields have been identified. As of June 2019, there have been 56 power plants built in 27 of these fields with a current total installed capacity of 1,549 MWe that provides 8,168 GWh/yr to the grid. The hydrothermal potential of the nation has been estimated to be 4,500 MWe at a price of $US 0.10/kWh and with a 10 year purchase price guarantee.

Considerable attention has been given to exploration for EGS resources and wells have penetrated to 4,500 meters where temperatures in excess of 295°C have been recorded. The EGS potential has been estimated to be about 20,000 MWe using a price for power of $US 0.15/kWh with a 15 year price guarantee.

An interesting Turkish resource characteristic has been the presence, nation-wide, of significant amounts of CO_2 that is generated by reactions between the carbonate reservoir formations at depth and the thermal waters. Since the initiation of widespread geothermal resource drilling, the CO_2 pressures have decreased. Consequentially, the use of more downhole pumps has been necessitated since the CO_2, while being a negative factor for power yield, facilitated artesian flows and has been used in local bottling work on site.

Since 2015, 200 production wells and 90 injection wells have been drilled, yielding a power generation increase from 721 MWe to 1,549 MWe. Turkey now has 48 MWe under construction (~253 GWh/yr); and funds have been committed but construction not yet begun for ~ 332 MWe estimated to yield ~ 1,751 GWh/yr of energy.

Investments on research and development from 2015 to 2019 totaled $US 2.3 billion and for field development and drilling they were $US 1.2 billion for a total of $US 3.3 billion. The private sector funded 90% of this sum and public sources covered the remaining 10%.

2.29 U.S.A.

Though the United States of America (USA) leads the world in the generation of geothermal power with a 2019 total installed capacity of ~3,700 MWe (18.4 TWh/yr), no new geothermal fields were developed in the period 2015-2019. Instead, there was considerable re-powering, consolidation, co-location with other renewable energy types, focus on improved performance in hot climates by combining air and water cooling systems, and expansions of existing fields. This trend can be attributed to continuing and increasing competition from low cost renewable energy resources such as solar, wind, and gas and the expiration of previously existing federal and state tax incentives. Despite these non-technical constraints, geothermal power generated in the past five years grew by 7-10% thanks to the measures described above.

Geothermal power is generated primarily in California (2,683 MWe) and Nevada (795 MWe) with the remaining energy coming from power plants in Alaska, Hawaii, Idaho, New Mexico, Oregon, and Utah. Exploration has been conducted in seven other western and southern states, but no new power plants have been built or begun. Data furnished showed total installed capacity of 3,806 MWe in 2018 (16 TWh/yr) and planned generation additions of at least 111 MWe by 2023 (approximately 40 MWe per year). USA geothermal power currently comprises about 2% of all renewable sources and about 0.4% of the total national power generation.

The U.S. Department of Energy through its sub-entities has funded numerous grass-roots programs focused on various topics designed to improve the rate of geothermal development. These programs relate to both hydrothermal and EGS resources and are broad-reaching and innovative. A brief summary of these programs includes:

- *GeoVision* – Highlights technical improvements, permit timeline optimization, air quality improvement using more geothermal, and reducing water consumption.
- Advanced Energy Storage – Addresses reservoir energy storage, flexibility of distribution, and improved dispatchability.
- Beyond LCOE- $US4.4 million – Goals of power plant cost reductions and system cost and value studies
- EGS Collab - $US 27 million – Studies at Sanford Underground Research facility, located in the town of Lead, South Dakota. Three EGS fracture related experiments in progress.
- Efficient Drilling for Geothermal Energy (EDGE) - $US 15.4 million – Seeks to improve drilling techniques and lower costs by reducing non-drilling time.
- FORGE - $US 156 million – Three phases through 2024. Selection of an optimal site for EGS studies and experiments.
- Machine Learning for Geothermal Energy - $US 5.5 million – Maximize value of existing datasets using ML.
- Play Fairway Analysis - $US 15.2 million – Three phases to identify and confirm blind resource targets.
- Waterless Stimulation - $US 4.3 million – Minimization of water resources for fracture creation, expansion and propping.
- Zonal Isolation for Manmade Geothermal Reservoirs - $US 4.5 million – Target and isolate specific wellbore zones for stimulation, production, and/or reinjection.
- The USA geothermal industry is also a member and participant in the following international groups:

The New Zealand Cooperative – For joint collaboration in creation of modeling tools, mineral recovery from thermal fluids, direct use, and the study of super-critical systems.

GEOTHERMICA Consortium – Provision of financial and technical expertise using members from 18 research and development entities based in 14 nations.

Finally, the USA geothermal community participates in the activities of:

- The International Energy Association that promotes the *adoption* of geothermal energy worldwide.
- The International Partnership for Geothermal Technology (IPGT) whose objective is to accelerate geothermal *technology* development, and
- The Global Geothermal Alliance which also has the purpose of *increasing* geothermal use internationally.

2.30 Other Nations Planning Near-Term Geothermal Development

2.30.1 Caribbean Nations

2.30.1.1 Dominica

The geothermal resources of Dominica have been studied for more than 30 years by United Nations workers, agencies of the US and French governments and by workers collaborating with international lenders. A great deal of geoscientific data was collected in the several prospective areas and in 2013 the Government of Dominica, with Multi-Lateral Development Bank assistance, sponsored the drilling of three slim exploration holes in the Wotton Waven area. Temperatures above 235ºC were recorded in these wells and between 2014 and 2015, the first of three planned production wells was drilled with similar temperatures encountered at a depth of just over 1,500 meters. In October 2019, well WW-P1 at Laudat was reopened after being shut in for 5 years. Hydrogen sulfide gas was bled off and two weeks of testing was begun.

Plans are reportedly to build a 7 MW (2 x 3.5 MW) power plant initially, which will contribute significantly to the current power demand of the island. The project is now under the control of a special purpose entity called Dominica Geothermal Development Company that is prepared to spend $US 50 million of national funds. Technical assistance has been provided by Jacobs New Zealand Limited and the Agence Francaise de Development. An ESIA has been completed, the gathering and injection line routes have been surveyed, and the power plant is anticipated to be on line in 2021.

2.30.1.2 Montserrat

The geothermal potential of Montserrat was studied prior to and following the eruptions of the Soufriere Hills volcano in 1995, and this led to the drilling of two exploratory wells in excess of 2,350 meters deep by the Icelandic Drilling Company under contract to the United Kingdom Department for International Development (DFID). Temperatures of 298ºC were recorded and in 2019, a third well, Mon-3, was begun so as to ultimately have the two production wells and one injection well required to service a 2.5 to 3.5 MWe power plant. Unfortunately, this well encountered mechanical difficulties and had to be abandoned before reaching the target depth. Despite this, plans are still to build the power plant using steam obtained from the Mon-1 and Mon-2 wells drilled prior to 2015. It is anticipated that this new facility will provide electricity enough for present and future domestic needs. Costs have been estimated at $US 20 million.

2.30.1.3 Nevis

In 2008, West Indies Power Company drilled three small diameter exploratory wells about 3.7 km apart, to depths ranging from 782 to 1,134 meters in the Spring Hill, Jessups, and Hamilton Estates areas. All three wells encountered temperatures in excess of 225ºC and significant steam was produced. Geothermometric projections suggest reservoir temperatures of at least 260ºC.

In November 2013, Nevis Renewable Energy International (NREI) was selected by the Nevis Island Administration to replace West Indies Power as the resource developer. In 2018, NREI contracted with DOSECC of Salt Lake City, Utah, USA to drill a slim-hole on the former Hamilton Estate site. The well, (N-4) was tested and found to have high permeability, a temperature of 256ºC, and other characteristics adequate for use to fuel a power plant. As of 2019, NREI now plans to identify funding sources and then build a 9 MWe net power plant to generate electricity for domestic use and, if possible, export power to nearby St. Kitts.

2.30.1.4 Saint Kitts

Notwithstanding the steaming fumaroles found in the crater of Mt. Liamuiga, the geothermal indicia on St. Kitts are less well defined than on some other Caribbean islands. In 2017 and 2018, surface exploration was conducted on the island by a French entity based in Guadeloupe. The work, funded by the Caribbean Development Bank and CARICOM, reportedly identified a potential for geothermal resources able to fuel 18-35 MWe of power. As of late 2019, no firm plans for further geothermal work have been announced though the dual-island state of St. Kitts and Nevis will receive EUR 5 million from the European Union to develop a sustainable energy sector and energy efficiency technologies for public facilities.

2.30.1.5 Saint Lucia

In 2015 and 2016, with funding from World Bank and the government of New Zealand, a comprehensive geoscientific study was conducted within and around the Qualibou depression. The work included geologic mapping, geochemical sampling, a gravity survey, an aeromagnetic survey, magneto-telluric and audio-magneto-telluric surveys, as well as a LIDAR survey. Interpretation of the results of this work indicated the existence of two prospective areas in the depression and another to the south. Currently, plans are to drill at least three slim holes in the recommended target areas. The goal is to discover geothermal resources that are chemically benign and still hot and abundant enough to fuel production of about 30 MWe in the early part of the 2020 decade.

The Government of Saint Lucia is collaborating with the World Bank while evaluating their position with regard to an existing Memorandum of Understanding. It is also negotiating with an experienced international development company to undertake production drilling and power plant design, construction, and operation.

2.30.1.6 Saint Vincent

In November 2018, Saint Vincent Geothermal Company, Ltd., Reykjavik Geothermal and Iceland Drilling Company signed a four-well contract in the hopes of confirming the existence of resources indicated via prior surface exploration studies. Development plans are for the generation of about 10 MWe and for a power plant to be on line in 2021 or 2022. Current work is being funded by the Caribbean Development Bank and the Inter-American Development Bank. Jacobs New Zealand Limited and Mannivit of Iceland will be primary engineering consultants on the project.

In May 2019, a full-size geothermal drill was moved onto a site at Bamboo Range, near Rabacca, in the north-central part of the island, just south of the Soufriere Volcano. The first well (well #1) was drilled to a depth of ~2,700 meters and is heating up preliminary to testing. Reportedly, permeability during drilling was marginal. In August, September, and October 2019 a second well (Well #3) was drilled in 83 days to a depth of about 2,800 meters. Initial recordings show a temperature of at least 215ºC and rising. Current plans call for: completion of drilling by December 2019, repair of well #1 by February 2020, the start of well testing in March 2020, and the beginning of a search for a power plant designer in August or September 2020 with the start of plant construction in early 2021.

2.31.2 Canada

The Canadian market poses several challenges to geothermal energy development. First, there exists a lack of early-stage supportive policies and funding programs, both provincially and federally. Also, several provincial and territorial jurisdictions have failed to develop regulatory frameworks for geothermal energy development. This creates an uncertain environment for investors and makes it difficult for developers to advance projects beyond the exploration phase.

In order to change the above-described situation, some initiatives have begun. These include: maintenance of the Canadian National Geothermal Database, provincial and territorial geothermal favorability mapping, energy literacy improvement programs, and various efforts on the part of the Canadian Geothermal Industry Association to build provincial and federal policy support for the geothermal industry.

There are currently 8 geothermal power production projects in various stages of exploration. These range from permit acquisition, to conduct of surface geoscientific studies, to drilling of well(s), to building of demonstration facilities. This work is being undertaken in British Columbia (3), the Northwest Territories (1), the Yukon Territory (1), Alberta (2), and Saskatchewan (1).

The province of British Columbia has some of the highest quality geothermal resources in Canada. Electricity and/or heat generation projects represent a path for rural and remote communities to achieve energy security and independence. There are currently two projects in development in British Columbia undertaken by Borealis GeoPower: The Canoe Reach project 30km south of Valemount and the Lakelse project 10km south of Terrace. The Canoe Reach project plans to develop a multi-phased GeoHeat Park where local businesses utilize geothermal heat; electricity generation will comprise the second phase of this project. The Lakelse project is also considering inclusion of a GeoHeat Park and a later phase featuring a 15MWe power plant.

There are two demonstration projects currently underway in the province of Alberta: 1) An Alberta Innovates-funded project in the Swan Hills oil field that is considering production of 3 -5MWe of electricity with co-produced fluids and, 2) A project conducted by E3 Metals Corp that will utilize geothermal energy to decarbonize their petro-lithium extraction facility. In addition, Terrapin Geothermics and two partners have received $US 25 million national funding for their planned “Alberta No.1” 5 MWe project that will generate heat as well as power.

Finally, in Saskatchewan, a geothermal developer in Estevan signed an Electricity Purchasing Agreement with the provincial government in November 2018. The Estevan project proponents hope to become the first geothermal electricity production facility in Canada, providing 5 MWe of electricity to the grid, and heat to a greenhouse.

2.30.3 Greece

Despite exploration and development that resulted in construction of a 2 MWe power plant on Milos in the 1970s, the plant was shut down: 1) because of excessive scaling and 2) to appease its unpopularity among the citizens. Drilling on Nisyros in the same decade revealed a very high temperature resource (>320ºC) but one having very aggressive (disqualifying) chemistry. Accordingly, currently Greece has no geothermally fueled power plants.

In 2018, Public Power Corporation (PPC) circulated an international tender to develop high temperature resources known to exist on Lesvos, Methana, Nisyros, and the Milos-Kimolos complex. Helector S.A. won the right to partner with PPC and it seems possible that new development activities may begin on Lesvos and/or Methana areas in the not-to-distant future. The National Energy and Climate Plan of 2019 predicts that geothermal power will aggregate 100 MWe by 2030 and 300 MWe by 2040.

2.30.4 Iran

The potential for geothermal development in Iran is large with regard to low, moderate, and high temperature resources. Thermal spring temperatures range from ~20ºC to ~80ºC. Sites in 14 regions of the country are considered to be prospective. Among these, the Sabalan region appears to host the best resources with the Meshkinshahr field currently having priority for installation of a geothermal power plant. Surface geoscientific exploration, drilling, and resource assessment have been completed. Reservoir numerical modeling and project-wide feasibility studies suggest that the viability of building a 5 MWe power plant, within a 5 km^2 field area has been proved. Future extension of the field to ~20 km^2 may be possible in which case an ultimate total of ~250 MWe of installed capacity might be attained.

During the period 2015 to 2019, 13 wells were drilled for electrical power project(s) and $US 22 million were spent, all of it coming from public funds. By 2020, the total installed geothermal power capacity of Iran is expected to by 5 MWe, providing energy of 35 GWh/yr. to the northern grid.

2.30.5 Ecuador

In Nov. 2017, the first deep Ecuadorian geothermal exploration well, PEC-1 was drilled in the Chachimbiro prospect. The well, a $6^1/_8$ inch diameter slim hole, is located at an elevation of 3,460 m and reached a depth of 1,978 m where a BHT of 235 °C was recorded. It was drilled using grants and technical assistance from JICA to CELEC, the national utility. A follow up stage, to be funded by a JICA government to government loan, may comprise the drilling 5 additional resource confirmation wells and the installation of a 5 MWe wellhead unit. If this project phase is successful, expansion of the field to 50 MWe may be considered.

Chachimbiro is the first of 11 prospects to complete the prefeasibility stage with the drilling of a successful deep exploration well. Three other high temperature prospects, namely Chacana-Jamanco, Chacana-Cachiyacu and Tufiño-Chiles, and one low temperature prospect, Chalpatán, are almost at the deep drilling stage. The other six prospects are Chalupas, Guapán, Chimborazo, Chacana-Oyacachi, Baños de Cuenca and Alcedo, all of which are awaiting government funding to complete prefeasibility studies and identify sites for deep exploratory wells.

From 2015 through 2019, 111 person-years of effort were undertaken by staff of the Ecuadorian government, the national utility, universities, and from foreign aid donor entities. A total of ~$US 22.57 million was spent on geothermal work with 30% coming from public sources and 70% from the private sector.

3. CONCLUSIONS

Though the number of nations now using geothermal energy to generate electricity is still small in comparison to the many countries that use their thermal resources for district or space heating, agriculture and aquaculture, and/or light industrial purposes, it is gratifying to note that there are new lands joining the former category. Since 2015, these include Belgium, Chile, Croatia, Honduras, and Hungary. Additionally, in the decade beginning in 2020, it is possible that newly or greatly increased geothermally generated power will be on line in Argentina, Australia, Canada, China, Dominica, Ecuador, Greece, Iran, Montserrat, Nevis, Saint Lucia, Saint Vincent, and Taiwan. Also, several African nations adjacent to the East African Rift Zone such as Tanzania, Uganda, Rwanda, and Malawi that are now being explored. Though these initial forays into geothermal power may be relatively small (less than 20 MWe), this renewable power may comprise a significant portion of the national power demands and add to the growing international trend towards green power.

The countries having the greatest total installed geothermal capacity (in descending order) are: the USA, Indonesia, the Philippines, Turkey, New Zealand, Mexico, Italy, Kenya, Japan, and Costa Rica. Indonesia hosts four of the worlds' largest power plants with Gunung Salak the biggest at 375 MWe. At the announced rate that Indonesia plans to develop more of their very considerable geothermal resources, it may be possible that they could surpass the USA and become the global market leader by about 2027.

It is very encouraging to see the documentation of significant growth percentages in the total installed capacities by Turkey (1,074 MWe), Indonesia (998 MWe), Kenya (599 MWe), USA (234 MWe), Iceland (73 MWe), New Zealand (59 MWe), China (19.5 MWe), and Germany (16 MWe). In the last 5 years, there has also been increased attention shown to the possibilities of developing Engineered Geothermal Systems (EGS) so as to tap the vast thermal energy resources now trapped in rocks having low natural permeability. This work is ongoing in countries that include the USA, Iceland, Britain, Germany, China, Portugal, and the Netherlands.

Over all, it should be noted that the initial, high risk phases of new and expanded uses of geothermal resources are being funded by federal government agencies, quasi-federal entities, and international multi-lateral lending banks rather than private industry. Turkey, the Philippines, and the USA appear to be the only exceptions to this trend. The early stage involvement of public funds is a way to mitigate the risks perceived by private investors. Once suspected resources have been discovered, characterized, and their extent preliminarily delineated, prospects can be transferred to the private sector for conduct of confirmation, development, production, and injection-well drilling, power plant design and construction together with finalization of all activities required to get newly generated power to the national grids. Judging from comments made in several WGC 2020 Country Update papers, it seems likely that this sequence of geothermal development will continue into the next decade due to global economic and political uncertainties that negatively impact the willingness of most private investors to be pioneers.

Finally, it is obvious from a glance at Figure 2, that that the prediction for a 18.5% rate of growth of geothermally-generated electric power between 2020 and 2025 is below the ~25% growth rate recorded over the past 10 years or so. It is believed that this dramatic decrease is primarily due to: 1) competition from wind, solar, and frac-produced natural gas-powered installations having lower perceived risks, shorter pay-out periods and lower costs per kWh. It may also be attributed to 2) the continued slow rate of adoption of geothermal-specific policies, laws, rules, and regulations in some nations and to 3) bureaucratic delays that greatly increase the time, cost and risk required to: obtain land access, mitigate local property, environmental, spiritual, and other objections/barriers, obtain all required permits, and finally to explore for, develop, construct and commission all aspects of a geothermal field, power plant, and transmission facilities. The latter can stretch the time needed to complete geothermal projects out to multiple years as compared to the single year or even several months typically required to build and operate wind and solar generating stations.

Hopefully, the situation described above can be overcome or at least ameliorated so that the growth rate of geothermal power internationally can return to its past levels.

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