The global energy sector is facing challenges like sharp increase in demand, climate change, and shortage of fossil fuels. Energy sector is booming and growing at a sustained rate with exciting new opportunities arising around the globe. Many countries acknowledge the threats caused by the climate change and realize the value of renewable energy. Geothermal energy is one such clean, sustainable and renewable source of energy. Geothermal energy can be used both for commercial power generation and direct uses such as heating and cooling applications.

Prime Minister Shri Narendra Modi has set a renewable energy target of 175 GW by the year 2022 for India and geothermal energy can play an important role in contributing to this target. Iceland has already achieved 90 per cent of its energy utilization from renewable energy sources with geothermal contributing a huge part in providing electricity, space heating and other direct applications. Icelandic geothermal experts are presently working in geothermal projects around the globe and participation of these experts at the conference will bring valuable insights on utilization of geothermal energy.

The International Conference on Geothermal Energy (2018) was organized by Centre of Excellence for Geothermal Energy (CEGE), Pandit Deendayal Petroleum University (PDPU) in partnership with the Embassy of Iceland in New Delhi. This conference will provide a unique platform where experts from different spectra of geothermal fraternity will be discussing issues and challenges in geothermal exploration and exploitation.
## ORGANIZING TEAM

<table>
<thead>
<tr>
<th>Role</th>
<th>Name and Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>PATRON-IN-CHIEF</td>
<td>PROF. T. Kishen Kumar REDDY, DIRECTOR GENERAL, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>PATRON</td>
<td>PROF. ANIRBID SIRCAR, HEAD CEGE &amp; DIRECTOR SPT, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>CONVENER</td>
<td>Mr. SHISHIR CHANDRA, COORDINATOR CEGE, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>CONFERENCE COORDINATOR</td>
<td>Mr. DWIJEN VAIDYA, RESEARCH ASSOCIATE CEGE, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>PUBLIC RELATION OFFICER</td>
<td>Mr. MANAN SHAH, RESEARCH SCIENTIST CEGE, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>LOGISTICS HEAD</td>
<td>MS. KRITI YADAV, RESEARCH ASSOCIATE CEGE, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>ORGANIZER</td>
<td>Ms. NAMRATA BIST, FACULTY SPT, PDPU, Gandhinagar</td>
</tr>
<tr>
<td>ORGANIZER</td>
<td>Mr. HARI GANESH, FACULTY SPT, PDPU, Gandhinagar</td>
</tr>
</tbody>
</table>
DG PDPU

“The need of the hour is to address the burning issues and obstacles in making geothermal energy mainstream source of energy and making it commercially viable. Government of Gujarat has given PDPU a big responsibility to carry out R&D activities in the area of geothermal energy. The Centre of Excellence for Geothermal Energy, CEGE, under the leadership of Dr. Sircar, along with research scientists of CEGE is working to fulfil the Geothermal Energy dream of India. Energy and Petrochemicals Department, Government of Gujarat and Gujarat Power Corporation Ltd (GPCL) consistently support PDPU in this mission.”

HEAD CEGE & DIRECTOR SPT

“Prof. Sircar discussed in detail the achievements of CEGE, since its inception. A brief excerpt of his talk is as follows. In order to put Gujarat on unconventional energy basket in India, Government of Gujarat (GoG) took an initiative of establishing a centre dedicated to research & development activities in the area of exploration and exploitation of geothermal energy. CEGE, since its inception, is carrying out extensive research in the area of geothermal exploration and exploitation. CEGE has completed surface exploration techniques such as Remote sensing studies, Geochemical studies, 2D and 3D
Magnetotelluric (MT), Gravity and Seismic survey and drilling of shallow bore well(s) to identify the location of geothermal reserves in three study areas namely, Dholera, Unai and Gandhar”.

H.E. THORIR IBSEN

“India could have considerable use of geothermal energy both for production of electricity and for direct use. Available estimates suggest that the geothermal potential in India could be in the order of 10 GW. However, major projects have yet to be embarked upon to harness this energy. Yet it is clear that India will be requiring diverse sources of renewable energy to meet its ambitious renewable energy target and indeed India’s commitment under the Paris Climate Agreement. Geothermal energy would be a valuable contribution to increase the share of renewables in the energy supply of India, considering the uncontested benefits of geothermal energy.
Signing of Memorandum of Understanding (MoU)

Signing of MoU with Iceland GeoSurvey (ISOR)

Signing of MoU with ONGC Energy Centre

Signing of MoU with GeoSyndicate Power P. Ltd.

Signing of MoU with LREDA-LAHDC

Signing of MoU with Arya Drillers

Signing of MoU with JKSPDC
SESSION- I
GEOTHERMAL POTENTIAL GANDHAR OIL FIELD AREA

Puneet Kishore,
GM-Head-ONCG Energy Centre

BACKGROUND:

• ONGC exploring Indian Basins for oil & gas for past 6 decades
• ONGC discovered 6 out of 7 oil & gas producing basins
• Large knowledge and data base on geo-scientific, well and production information.
• In 2011 ONGC Energy Centre decided to evaluate geothermal energy prospects in sedimentary basins.
  – A collaborative agreement was signed with M/s Talboom, a Belgian company

TALBOOM STUDY:

• Assessment of subsurface through systematic & iterative approach
• In 3 phases:
  – Phase-1: Data Compilation
  – Phase 2: Investigation of specific Area
    • Assess Potential of the prospective area
  – Phase- 3: Investigation of specific Site(s)
    • Assess feasibility of Pilot project
• Phase-1: Identified Cambay Basin
• Phase-2: For identified Area
  – Determination of petro-physical parameters from well logging and thermal conductivity data
  – Built geological structural model based on seismic profiles, stratigraphy from wells, contour maps, etc.
  – Numerical modelling to estimate spatial distribution of temperature
Geological data for almost 4000 Sq. km. was studied to arrive at 400-800 Sq. Km. for next phase of investigation.
RESERVOIR SIMULATION STUDY:

- Delineated high temperature isotherms in Gandhar area
- Hazad Sand - ideal geothermal reservoir due to thick sand (~200 m) with favorable properties
- Reservoir Temp: 120 to 160°C
- Modelled area marked by green box (10 km x 10km)
- Reservoir estimated at 400MW electric

Modelled Temperature distribution on top of Sand (between 140-150°C)

Geological Section along W-E with Temperature

Colours represent different geological units.

Hazad member
Thermal Modelling study by KDMIPE, ONGC March 2017

Objective and Approach
• Validate and fine tune geothermal potential of Gandhar area
• Static Geological model used for thermal modeling
• Model uses 8 depth maps at key stratigraphic levels along with present day tomography
• Final model geometry has 31 sub-layers based on spatio-temporal facies variation, paleogeography analysis and computed average porosity / permeability from core data.

Facies Maps
• Hazad member has been divided into three main units from bottom to top by analyzing well data and electrolog correlation i.e.
  • Lower Hazad- Sand-A unit (GS-0 to GS-3 sands)
  • Middle Hazad- Sand-B unit (GS-4 to GS-9 sands)
  • Upper Hazad - Sand-C unit (GS-10 to GS-12 sands)
  • These three units are separated by thin shale layer.

Electrolog correlation of Hazad sands – NW to SE
Model Geometry - Top of Hazard Units A, B, C

Unit - C

Unit - B

Fig. 2.7.2: Facies Map - Middle Eocene (Unit-A)

Fig. 2.7.3: Facies Map - Middle Eocene (Unit-B)

Fig. 2.7.4: Facies Map - Middle Eocene (Unit-C)
Overlay of facies, depth & temperature

Unit -A

Unit -B

Unit -C
Geothermal Potential
Based on analysis of all the geothermal elements, a favorable geothermal system is envisaged in the central part of Gandhar-Pakhajan area apart from the Nada area.

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit C</th>
<th>Unit B</th>
<th>Unit A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reservoir Area (&gt;130°C), km²</td>
<td>453</td>
<td>689</td>
<td>917</td>
</tr>
<tr>
<td>Reservoir Thickness, m</td>
<td>40</td>
<td>110</td>
<td>50</td>
</tr>
<tr>
<td>Avg. reservoir Temp °C</td>
<td>137.5</td>
<td>138.75</td>
<td>140</td>
</tr>
<tr>
<td>Conversion to elec. through ORC, @10%, Billion Units</td>
<td>29.7</td>
<td>126.1</td>
<td>77.4</td>
</tr>
<tr>
<td>Plant rating @25 yrs, MW</td>
<td>151</td>
<td>642</td>
<td>394</td>
</tr>
<tr>
<td>Total geothermal resource</td>
<td></td>
<td></td>
<td>1187 MW</td>
</tr>
</tbody>
</table>

Development of Pilot Geothermal project

Different sites considered for pilot project
Summary dynamic modeling- Doublets in Sites-1 & 2 by Talboom

- Production temperature of 130°C/ 140°C is sustainable
- Required permeability to sustain high volume water production (300 m³/h), is surely within the range of Hazad sands (with multiple sands being opened)
- Permeability (k) ranging from 100 mD to 300 mD is within expectation, lower k will increase inlet pressure.
- Spacing of wells needs to be 1500m to be sustainable over 30 years
- Constant geothermal production: no declining of “heat reservoir”
- Multiple doublets can be achieved from the same reservoir

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<tr>
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<th>Model Location 1</th>
<th>Model Location 2</th>
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<tr>
<td>Key-well</td>
<td>GNDR-526</td>
<td>PKJ-14</td>
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<tr>
<td>T (Production)</td>
<td>133 °C (calculated)</td>
<td>145°C (aim)</td>
</tr>
<tr>
<td>Depth Top reservoir (m)</td>
<td>3200 m</td>
<td>3600 m</td>
</tr>
<tr>
<td>Gross power capacity (kW)</td>
<td>2700 kW</td>
<td>3800 kW</td>
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<tr>
<td>Net power capacity (sellable) (kW)</td>
<td>1500 kW</td>
<td>2600 kW</td>
</tr>
<tr>
<td>ORC efficiency (%)</td>
<td>10%</td>
<td>12%</td>
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</table>

Pilot Test Site Selection
- Need Doublet (producer and injector) of wells with spacing about 1.5 km
- In order to save cost of drilling new geothermal wells, OEC decided to examine feasibility of using pre-existing drilled wells
  - Having highest temperature
  - Best geothermal reservoir properties
  - Non-flowing / abandoned wells without casing retrieval
- Identified site-3
Contour map of top of Hazad layer- Geothermal prospect (Site-3)

- Structurally Bounded by faults on East & West
- Sand Dipping from North to south
- Seven wells available and status reviewed - Four non-flowing and three abandoned (plugged, casing not retrieved)

Plan for Pilot development

- Phase-1: Assess geothermal potential of existing wells
  - Assess health of casing / well
  - Testing Hazad in small intervals by lifting water for:
    - Productivity Index
    - Injectivity
- Phase-2: Set up Geothermal Pilot plant
  - Design, procurement and re-completion of wells for geothermal
  - EPC of ORC plant

Wells for Geothermal project

- Based on hydrodynamic connectivity and desired spacing, selected pair G-345 & G-205 out of seven identified wells.
- G#345 identified as producer well & G#205 as injector well for pilot study in Geothermal doublet.
G#345 Assessment

- Rig deployed during Nov-Dec 2016 for testing.
  - Well condition found OK
  - Pre-existing packers could not be released
  - Tubing was cut above the packers
  - Fish could not be released
  - Testing to be taken up again

G#205 Assessment

- Rig deployed in June-July’17 for testing
- Well condition found to be OK
- Tested sands GS-7 and GS-9 (Mid Hazard- Unit-B)
  - Found sub-hydrostatic regime
    - Static level at 348m (GS-7), 632m (GS-9)
  - Injectivity: 500 lpm @ 200 psi.
  - Ideal injector well for doublet

Conclusion

- Gandhar Geothermal potential:
  - Identified and modelled by Talboom – Belgium
    - 400 MWe in 100 km² area
  - Further modelling by KDMIPE-ONGC
    - Potential estimated ~ 1000 MWe for 25 years
- Doublet for pilot project
  - Suitability & potential of existing non-flowing wells being assessed
    - Injector well tested and found suitable
- OEC also prospecting other Hi-Temp sedimentary areas for geothermal potential
CENTRE OF EXCELLENCE FOR GEOTHERMAL ENERGY “JOURNEY TILL DATE”
Anirbid Sircar
Head- CEGE, PDPU

About CEGE
- In order to put Gujarat on unconventional energy basket in India, Government of Gujarat (GoG) took an initiative of establishing a centre dedicated to research & development activities in the area of exploration and exploitation of geothermal energy.
- CEGE, since its inception, is carrying out extensive research in the area of geothermal exploration and exploitation.
- CEGE has completed surface exploration techniques such as Remote sensing studies, Geochemical studies, 2D and 3D Magnetotelluric (MT), Gravity and Seismic survey and drilling of shallow bore well(s) to identify the location of geothermal reserves in three study areas namely, Dholera, Unai and Gandhar.
- CEGE has successful established India’s first *Heat Pump Based Geothermal Heating And Cooling System* at Dholera.

Pre-feasibility Studies
- Remote Sensing
- Geochemical Study

Exploration Activities
1. Surface Exploration Activities in Dholera.
2. Surface Exploration Activities in Unai.
3. Surface Exploration Activities in Gandhar.
4. Drilling of Shallow bore wells at Dholera.

Exploitation Activities
1. Space Heating/ Cooling system
2. Setup of ORC.
3. Direct Applications of geothermal energy.

- According to GSI report, 17 hot springs were identified in Gujarat, India.
- Integrating geological studies, geochemical studies and remote sensing of all the locations, six locations (Unai, Tulsishyam, Tuwa, Dholera, Chabsar & Gandhar) were identified for further investigation.

<table>
<thead>
<tr>
<th>Location</th>
<th>LAT / LONG</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chabsar⁴</td>
<td>22°48' 72°16'</td>
</tr>
<tr>
<td>Gambay Wells</td>
<td>22°14' 72°41'</td>
</tr>
<tr>
<td>Gogha</td>
<td>21°41' 72°16'</td>
</tr>
<tr>
<td>Harpan</td>
<td>23°22' 73°05'</td>
</tr>
<tr>
<td>Kawa</td>
<td>22°04' 72°47'</td>
</tr>
<tr>
<td>Khedaapat</td>
<td>23°20' 73°56'</td>
</tr>
<tr>
<td>Khar</td>
<td>23°33' 66°00'</td>
</tr>
<tr>
<td>Maktapur</td>
<td>23°50' 72°22'</td>
</tr>
<tr>
<td>Warha</td>
<td>23°43' 71°43'</td>
</tr>
<tr>
<td>Mithapur</td>
<td>22°32' 74°01'</td>
</tr>
<tr>
<td>Unar*</td>
<td>20°51' 73°24'</td>
</tr>
<tr>
<td>Tuwa*</td>
<td>22°51' 73°34'</td>
</tr>
<tr>
<td>Tulsishyam*</td>
<td>21°08' 71°05'</td>
</tr>
<tr>
<td>Savarkundia</td>
<td>21°20' 71°19'</td>
</tr>
<tr>
<td>Losandumra</td>
<td>22°55' 73°12'</td>
</tr>
<tr>
<td>Lajpur</td>
<td>22°12' 69°48'</td>
</tr>
<tr>
<td>Dholera*</td>
<td>23°15' 72°12'</td>
</tr>
</tbody>
</table>
The geological and geophysical investigation in Dholera, Gujarat, India depicted that geothermal potential exists in the study area. Integration of surface and subsurface data helped to prepare subsurface anomaly cross-sections. The conductive bodies are clearly brought out using geoelectric models of the subsurface stratified earth layers. The data was interpreted using 1D Occam inversion and 2D nonlinear inversion techniques. There is low resistivity anomalies sandwiched between high resistivity basaltic rocks. Also, the Geochemical study shows high fluoride levels which indicate that the water has interacted with subsurface mica and apatite bearing rocks. Drilling of wells over the identified prospects and temperature probe inside the boreholes will help to estimate the geothermal gradient inside the subsurface. The results will help in harnessing the energy for domestic and commercial uses.

### Geothermal Bore Well Dholera A01 & A02

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Well-1</th>
<th>Well-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth</td>
<td>1000 ft</td>
<td>1000 ft</td>
</tr>
<tr>
<td>Water temperature</td>
<td>47 °C</td>
<td>47 °C</td>
</tr>
<tr>
<td>Water flow rate</td>
<td>5 l/s</td>
<td>4 l/s</td>
</tr>
<tr>
<td>Data acquired</td>
<td>SP and Resistivity logs</td>
<td>Cutting data</td>
</tr>
<tr>
<td>Tubular diameter</td>
<td>8’</td>
<td>8’</td>
</tr>
<tr>
<td>Hole diameter</td>
<td>18’</td>
<td>18’</td>
</tr>
</tbody>
</table>
Exploitation Activities in Dholera

Other Exploitation Activities in Dholera

- The design of the Space Heating and Cooling and ORC is optimised for integration of both systems to achieve ultimate aim of generation of electricity through geothermal energy.
- Hot water output from heat pump system to be used as inlet for ORC. Minimum input temperature and flow rate for generating electricity through ORC are 77-80°C and 7-8 litre/sec respectively.
- Output of Pilot Scale ORC will be between 10-20 kW for the present site conditions.
- Based on the results of ORC system, the commercial viability of the system can be known for Indian conditions.
Surface Exploration Activities in Unai

- Unai thermal springs falls in the south-eastern part of the Mainland Gujarat. The terrain is largely covered with thick Deccan trap of Late Cretaceous to Early Eocene age.
- There are low-resistivity anomalies at depth 15 km below sea level. This may be associated with magma which is heating of rocks lying above this reservoir. So they are the possible location of the hot spots on surface.

- The parental fluid ascends through the high permeable zones developed along the faults. The high resistivity rock exists at the deep sub-surface and geothermal source exists at deep and shallow regions.
- We postulate that both are connected with fault system. The faults are normal in nature. The ascending hot fluid yields convective circulation systems beneath the cap rock.
- The fluid reaching shallower part may be of two phases or vapour dominated reservoir. Important outflow can be located on the MT at sites U-24 to U-30; nevertheless it could be present at other unidentified flows.

Surface Exploration Activities in Gandhar

- In Gandhar, CEGE is working in collaboration with OEC.
- OEC has already obtained EIA clearance for Gandhar.
- CEGE-OEC is working on drilled abandoned wells in Gandhar with possible Geothermal potential.
- Since resistivity of the focus area is low, and the background resistivity is also low, hot spots could not be identified in Gandhar, because no geoelectric anomalies were observed.

MT Profiles at Gandhar

Gravity Contouring at Gandhar
Other Exploration Activities in Gandhar

- Upward continuation (UC) filtering was carried out on gravity data. UC serves to smooth out near surface effects (Shorter wavelength anomalies) after calculating the gravity field at an elevation higher than that at which gravity is measured.
- On computation of Bouguer residual gravity data, six lines were selected to get the geologic model. Residual Bouguer gravity data was inverted using the algorithm of Talwani et al., 1959 and a contrast density of – 0.2 g/cm³ between basalts and shale. Geologic model corroborates well with MT data.

BACKGROUND

- With increasing global demand and challenges in energy sector, the requirement for renewable and environment friendly energy as well as energy efficient systems are need of the hour. In tropical countries like India, because of diverse geographical conditions and different climatic conditions throughout the year, both heating and cooling requirements are there in domestic, commercial and industrial areas.
- Current heating and cooling systems operate on fossil fuels, consume high amount of electrical energy and require continuous supply of water. However, these requirements can also be fulfilled using geothermal energy. Geothermal energy is a renewable, environment friendly and sustainable source of energy. By developing such systems, dependency on fossil fuels can be reduced drastically.
- GSHP system consists of Ground Heat Exchanger (GHE), refrigerating system and the indoor units. GSHP system can generally operate for both heating mode and cooling mode.

PATENT NUMBER: 201621037182
Applicant Name: Manan Shah, Dwijen Vaidya, Anirbid Sircar, Shreya Sahajpal and Shubhra Dhale
United Nations University Geothermal Training Programme

- UNU-GTP has operated in Iceland since 1979
- Aims at assisting developing nations with significant geothermal potential to build up expertise in most aspects of geothermal exploration and development. This we do through offering:
  - annual 6-month specialised training courses in Iceland for professionals in geothermal work, through UNU Fellowships, with weight on research projects, published in: *Geothermal Training in Iceland* and on our website: [www.unugtp.is](http://www.unugtp.is)
  - additional Fellowships to former UNU Fellows to further their geothermal knowledge through MSc and PhD studies in Iceland
  - annual Short Course series in two key geothermal regions: in East Africa, and in Latin America and the Caribbean Islands (LAC), from 2005/2006
  - general services of customer-designed sponsored courses in line with the needs of the customer
6-month training – time schedule

Admission Criteria for 6 the Month Studies

• The candidate must:
  • Hold a university degree
  • Have good command of English

• The candidate should:
  • Have one year practical experience in geothermal
  • Be under 40 years of age

• UNU-GTP PLACES EMPHASIS ON GENDER EQUALITY!
  • Over the long run the number of female and male Fellows from a particular country should be approximately equal

Participation in UNU-GTP in Iceland

1979 – 2017

• 670 scientists and engineers from 60 countries have completed the 6-month specialized course – now given in 8 different lines of study
• Thereof 149 are women (22%)
• MSc programme with University of Iceland since 2000, and now also Reykjavik University: 57 graduates – 10 enrolled (Nov. 2017)
• PhD programme with UI from 2008 – first two defended PhD thesis in 2013 and 2016 – currently 4 are pursuing their studies

Number of UNU fellows in Iceland 1979-2017
HOME Countries of UNU Fellows 1979-2017

UNU FELLOWS IN ICELAND 2016 the biggest group in Iceland to date – 34 UNU fellows (as in 2013)

6 month studies 2017: 23 students from 10 countries

- China: 2
- Djibouti: 2
- El Salvador: 1
- Ethiopia: 3
- India: 1
- Indonesia: 3
- Kenya: 7
- Malawi: 1
- Tanzania: 2
- Vietnam: 1

- Geothermal Geology: 4
- Geophysical Exploration: 0
- Reservoir Engineering and Borehole Geophysics: 6
- Chemistry of Thermal Fluids: 5
- Environmental Science: 0
- Geothermal Utilization: 5
- Drilling Technology: 3
- Project Management and Finances: 0
UNU FELLOWS IN ICELAND 2017 23 fellows from 10 countries | 1 from INDIA

6 month studies 1979–2017: top 10

- Kenya: 124 (18.5%) 1982-2017
- China: 87 (13.0%) 1980-2017
- Ethiopia: 41 (6.1%) 1983-2016
- El Salvador: 40 (6.0%) 1980-2017
- Philippines: 40 (6.0%) 1979-2015
- Indonesia: 32 (4.8%) 1982-2017
- Iran: 25 (3.7%) 1996-2016
- Costa Rica: 18 (2.7%) 1984-2011
- Djibouti: 17 (2.5%) 1989-2017
- Uganda: 17 (2.5%) 1990-2016

Number of 6 month Fellows per year

Cumulative number of 6 month Fellows
Indian fellows undertaking 6 MONTH STUDIES

<table>
<thead>
<tr>
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<th>Gender</th>
<th>Institution</th>
<th>Year</th>
<th>Field</th>
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<tbody>
<tr>
<td>Farooq Ahangar</td>
<td>Male</td>
<td>JKPDC</td>
<td>2012</td>
<td>Geothermal Utilization</td>
</tr>
<tr>
<td>Vijay Chauhan</td>
<td>Male</td>
<td>IIT</td>
<td>2013</td>
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</tr>
<tr>
<td>Kunzes Dolma</td>
<td>Female</td>
<td>LREDA</td>
<td>2017</td>
<td>Geothermal Utilization</td>
</tr>
</tbody>
</table>

Short courses in support of the UN development goals

- Special contribution of the Government of Iceland towards the **UN Millennium Development Goals** was support for geothermal training in two continents, Africa and Latin America and the Caribbean
  - Series of Annual Short Courses during 2005-2015 – in total 12 events in Africa with about **550 participants from 22 countries**, and 8 events in Central America with **410 participants**
  - Close cooperation partners in the African series have been the Kenyan energy companies **KenGen** (from the start) and **GDC** (from its establishment in 2009)
  - In 2016 these have been reorganised with launching of the new **SDG Short Course Series** taking aim in geothermal energy’s contribution to the **UN Sustainable Development Goals – SDGs** adopted for the period 2016-2030

UNU-GTP Millennium Short Courses 2005-2015

<table>
<thead>
<tr>
<th>UN MILLENNIUM WORKSHOP AND SHORT COURSES FOR E-AFRICA</th>
</tr>
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<tbody>
<tr>
<td><strong>Event</strong></td>
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<tr>
<td>Workshop for Decision Makers on Geothermal Projects and their Management</td>
</tr>
<tr>
<td>Short Course on Surface Exploration for Geothermal Resources</td>
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<tr>
<td>Short Course II on Surface Exploration for Geothermal Resources</td>
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<td>Short Course III on Exploration for Geothermal Resources</td>
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### Short Course/Workshop Participation

<table>
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<tr>
<th>Short Course / Workshop</th>
<th>Total</th>
<th>Home country</th>
<th>Neighboring countries</th>
<th>International</th>
<th>Iceland</th>
<th>UNU-Fellows</th>
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<td>Kenya 2005</td>
<td>16</td>
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<td>8 (50%)</td>
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<td>15 (75%)</td>
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<td>26 (74%)</td>
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<td>23 (68%)</td>
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<td>32 (64%)</td>
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<td>8 (53%)</td>
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Positive side consequences

- Through the UN Millennium Short Course series, UNU-GTP has been able to reach out to a much larger number of people than is possible through the training in Iceland
- The courses have proven a good venue for interviewing and selection of UNU Fellows for the more extensive training in Iceland
- The courses have also catalyzed increased regional cooperation, as well as being a venue for sharing knowledge between generations

launching of the new SDG short course series in 2016

- Held in support of the UN SDGs, in particular:
  - **Goal 7:** Ensure access to affordable, reliable, sustainable and modern energy for all
  - **Goal 12:** Take urgent action to combat climate change and its impacts
- Basic setup similar as in the earlier short courses series, but:
  - With greater attention to the concept of sustainability and actions to combat climate change
- First event in the LAC series launched in September with the “SDG Short Course I on Sustainability and Environmental Management of Geothermal Resource Utilization and the Role of Geothermal in Combatting Climate Change” held in El Salvador, September 4-10, with 68 participants – biggest event to date in El Salvador. In
September 17-23, 2017 “SDG Short Course II on Feasibility Studies for Geothermal Projects” was given, with 66 participants

- The launching of the new African series was with: “SDG Short Course I on Exploration and Development of Geothermal Resources” in Kenya, on November 10-30, with 61 participants. “SDG Short Course II …” was held in Kenya on November 9-29, 2017, with 63 participants.

Customer designed training activities

- Triggered by the urgent need for training in countries planning fast tracking of geothermal development – with the first events in 2010
- Made possible in part by the experience accumulated by running the Millennium Short Courses and education material prepared for them
- Have proven a good opportunity for some countries / institutions in need of a rapid capacity building process, beyond what the UNU-GTP can offer under its conventional operations

Examples of customer designed short courses and training activities
Support to regional geothermal training centres in the developing countries
• UNU-GTP was contracted to assess geothermal diploma courses run at the University of El Salvador in 2010 and 2012
• UNU-GTP continued to play an advisory role in the operation of the programme under the sponsorship of NDF/IDB in 2013-2015
• UNU-GTP is directly involved in the implementation of the programme, in cooperation with LaGeo S.A. de C.V., under sponsorship from NDF in 2016-2017
• There are plans for this cooperation to continue for the coming years
• UNU-GTP supports the establishment of a Geothermal Centre of Excellence in Kenya that will benefit Kenya and the neighboring countries

World Geothermal Congress - WGC2015, 96 UNU Fellows attended the Melbourne congress More than 260 papers FROM about 180 UNU FELLOWS accepted
Geological location of Iceland

- The Mid-Atlantic Ridge crosses the country and forms an active zone of volcanism and rifting from SW to NE.
- Iceland is also located on the NE-Atlantic hot spot.

Geothermal map of Iceland
Primary energy consumption in Iceland 1940-2016

Geothermal Power Stations in Iceland

Iceland GeoSurvey has been involved in all exploration, drilling consultancy, resource assessment and management of all geothermal power plants in Iceland.
Geothermal District Heating in Iceland

- Reykjavik Energy: 1000 MWth
- Húsavik: 40 MWth
- HS Orka: 150 MWth
- Hveragerði: 65 MWth
- Akureyri: 80 MWth

The environmental benefit

Before geothermal space heating:
Reykjavik in 1933 covered with smoke from coal heating.

With geothermal space heating:
Reykjavik in 2008, almost same view but without visible air pollution.

Few words on Iceland GeoSurvey (ÍSOR)
- ÍSOR is a non-profit governmental institution specialized in geothermal R&D since 1945.
- Provides worldwide services and consultancy in geothermal energy.
- Operates on competitive basis with no basic governmental funding.
• Has provided the scientific basis for the geothermal evolution in Iceland.

Employee’s 2016

In Reykjavik and Akureyri. Approximately 5-10 students each summer.

- 27 Geologists
- 21 Physicists and Geophysicists
- 08 Chemists and Geochemists
- 10 Other Academic Education
- 08 Engineers and Tecnologists
- 08 Other Education

Geothermal expertise at ÍSOR

- Geothermal exploration
- Drilling Consultancy
- Well Logging and Mud Logging
- Well Testing and Evaluation
- Resource Assessment
- Reservoir Management
- Geothermal Training
- Environmental Studies
ÍSOR provides internationally complete geothermal services and consultancy

Typical project cost of a geothermal power plant:

- Flash power plants: 3.5 – 4 MUSD/MW installed,
- Binary power plants: 5 – 6 MUSD/MW installed
- Binary Plants (~1-50 MW) usually are smaller than Flash Plants (~5-300 MW)
- Cost of drilling is around 40%, power plant construction around 40%, other 20%.
We need careful exploration:

- A deep exploration borehole in a high temperature field can cost several million USD.
- The total cost of geo-scientific exploration is only a small part of the cost of one such well.
- However, exploration requires considerable up-front cost prior to exploration drilling. Therefore:
  - Exploration methods must be selected with respect to the site
  - Exploration must be carried out in professional manner
  - Stepwise approach is recommended, i.e. the strategy must be revised as the results appear.

The selection of exploration methods

- The geology of geothermal fields are quite variable from one place to another.
- There is no single exploration procedure that can be applied universally to all geothermal fields.
• The selection of exploration methods must be tailor-made for each field.

• But we have guidelines to form suitable exploration strategy for each field.

**Geological and geochemical exploration**

• Geological mapping (lithology).

• Structural geology, tectonics
  (faults, fractures, dykes)

• Volcanology and volcanic history

• Hydrogeology

• Geo-hazards and environmental geology

• Geothermometers

• Chemical properties of the fluid

Does the surface activity relate to geological structures?

How hot is the geothermal reservoir?

Is the chemical content suitable for geothermal energy production?

**Geophysical Exploration**

• Resistivity – TEM (0-1 km) & MT (0-25 km)

• Micro seismicity (2-10 km)

• Heat flow

• Gravity

• Magnetics (dykes, faults)

• Seismic reflection (only in sedimentary rock)

How big is the active resource?

Define the drilling targets.

**The important resistivity measurements**

• The best available geophysical method or high temperature fields with T>230°C.
• Two main types, TEM and MT, should be used together.
• Has limitations and pitfalls must be avoided

**Resistivity structure of a typical simple high temperature field:**

- The resistive core shows a volume where temperature has reached at least 230°C for some period of time during the geological history of the geothermal field.
- It is not necessarily so hot today: If the hot resistive core cools down, the resistivity will not lower correspondingly. **This must be tested by drilling.**
- Hence the resistivity does not tell us where to drill to obtain 230°C – but it tells us definitely where not to drill.
- New or improved exploration methods are needed to predict temperature variations within the resistive core.

**Note:**
- The nature is never as simple as indicated on the previous slide. Usually much more complicated resistivity picture appear from real surveys.
- This raises two issues:
  - Is the method applied, both the measurement and interpretation technology sufficient and of high quality?
How do we interpret the real resistivity structure in terms of geothermal parameters like temperature, salinity, minerals, magma and permeability?

- We need communication and feedback mechanisms between exploration teams and the decision makers.

**Heat flow measurements are powerful tool to discover geothermal fields and locate geothermal fractures:**

- Can only be applied where the low permeability rock is close to the surface.
- Used in Iceland to detect low and medium temperature geothermal fields and locate permeable fractures as drilling target.

**Micro-seismicity**

Micro-seismicity is commonly associated with large geothermal fields, especially high temperature fields.

By careful seismic monitoring and precise location of the earthquakes we get information about active faults that might be target for drilling

**Seismic reflection**

Used to map out faults and fractures that could serve as aquifers.

Mainly applicable in geothermal areas within sedimentary basins.

Expensive method.
Concluding remarks

- Iceland has successfully built up geothermal industry that provides the country environmentally benign heat and power at low market prices.

- This is a result of 90 years of research and development where many obstacles were overcome.

- This success is based on:
  - Well prepared and performed exploration surveys.
  - Well planned drilling projects, well logging and supervision.
  - Initial governmental support actions and risk sharing funds.
  - General public acceptance.
EXPLORATION DRILLING WITH FOCUS ON SLIM WELLS

Bjarni Richter
Director, Geothermal Energy, ISOR

Definition of exploration drilling

- International Finance Corporation (World Bank Group) classified wells in the following way: “... the first five wells drilled in a field are deemed to be exploration wells (in practice this could vary from anywhere between two and 10 wells) ...”

- From OpenEI wiki: Exploration Drilling: Exploratory drilling is the Initial phase of drilling for the purpose of determining the physical properties and boundaries of a reservoir. There are several different exploratory drilling techniques: core holes, exploratory wells, slim holes, and thermal gradient holes.

- Relatively shallow exploration wells <2000 m have been drilled as slimholes but deeper holes are often of the same type as production wells.

Exploration Drilling (sub-surface exploration)

- Testing the results of the geophysical exploration

- Confirming/updating the conceptual model by combining results

- Confirming the temperature estimation of surface sampling

- Confirming the chemical composition of the brine

- Flow testing the reservoir

- Update the reservoir model, through simulation

- To confirm the existence of a viable resource and how to utilize it

The goal is to bring the knowledge and confidence of the geothermal resource to a level that meets the requirements of a “Measured” resource, which is usually is the condition for financing the next steps.
Most common casing programs for geothermal HT wells

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<th>Slim</th>
<th>Cored</th>
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<td>290.7 mm casing</td>
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<td>5. stage</td>
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<tr>
<td>282.5 mm bit</td>
<td>1500 mm casing</td>
<td>2450 mm casing</td>
<td>2040 mm casing</td>
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<tr>
<td>3. stage</td>
<td>4. stage</td>
<td>5. stage</td>
<td>6. stage</td>
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<tr>
<td>210.9 mm bit</td>
<td>1500 mm casing</td>
<td>2450 mm casing</td>
<td>2040 mm casing</td>
</tr>
</tbody>
</table>

Selection of drill rig through hook load rating for different drilling

- The diagram shows how deep a particular rig can go, based on its hook load capacity (t) and diameter of drill pipes.
- The weight (in water) of casings is shown as dotted lines.
- NQ and HQ are light weight coring drilling rods.
- Examples for small rigs of 100 t and 50 t hook load are shown for reference, with a safety factor (SF) of 1.33.
Standard well design for a regular, high temperature geothermal well

Cored well design for HT (slimhole)

Modifications from normal coring is required for geothermal drilling, especially high temperature or where gas is expected:

- Conductor and anchor casing need to be stronger (API) and with an added clearance (annulus) for cementing. Drill with tricone bit or ream.

- Production casing is cemented in spite of small annulus.

- Casing head has two side outlets for kill and choke with a dedicated extra pump for use after circulation loss.

- Wellhead consist of a master valve, annular blowout preventer and a stripper to seal around the drill pipes. Installation requires a cellar.

- A lubricator is required for tripping-in to retrieve core barrel in case of a kick.
• A NQ technical casing can be installed from the wellhead T-ee to ~250 m depth to stimulate the well to self-flow by air lifting.

• Can be geophysically logged and flow tested.

• Can be a minor producer, if successful, or a monitoring well.

**Slimhole 2¼" (NQ)**

• This well is drilled with a coring rig, the last two sections HQ and NQ.

• The coring rigs are truck mounted and typically have a hook load of 20 t.

• The rig requires a substructure and a cellar for the BOPES.

• Can be geophysically logged and flow tested.

• Can be a minor producer, if successful, or a monitoring well.
**Slimhole 6 ⅛”**

- This slimhole can be drilled with rigs of 60 to 100 t hook load cap.
- Such rigs are truck mounted or on a trailer and require a substructure or alternatively a deep cellar.
- Can be geophysically logged and flow tested.
- The wells are drilled with conventional tri-cone bits.
- Such wells can reach 2000-2500 m, depending on the drill string and hook load rating of the rig.
- Can be a small producer if temperature and permeability allows.

**BOP stack for slimhole drilling (coring or tricone)**

Each stage of drilling requires a new stack to suit the diameters and safety requirements. On the last stage the final master valve has been installed.

When doing high temperature coring well or wells that may experience high pressure, you need a lubricator for the core barrels.
Why a slimhole?

• High cost of drilling is a barrier to exploration for subsurface resources.
• Remote locations – difficult access. Easier transportation. Less infrastructure.
• The reduction in bulk allows helicopter transport or small trailer mounting.
• The smaller size reduces location area (about 1000 m$^2$ with mud pits).
• The power required is low, typically 300-400 hp, saves fuel.
• Sensitive areas – minimum footprint needed.
• Slimhole drilling = reduced costs – 25-75% (Finger, 1994)
• Cheaper drilling tools, casing, cement jobs.
• Shorter rig mobilization and de-mob time.
• Smaller crews, fewer materials.
• Provides information on the resource temperature, pressure and composition and also indications of permeability and output.
• Continuous cores provides high definition stratigraphic information and samples for determination of reservoir properties.

Slimhole rig

Mobile rig for drilling thermal gradient wells and slim production wells to 1100 m.
Coring rig

- Compact size of a coring rig.
- No substructure requires a deep cellar for wellhead and BOP.

Rough average cost estimation of different well types:

- HT Production wells, regular size (8 ½“ final diameter, up to 3000 m): ~2000-2500 USD/m. (Shallow wells usually the higher cost per meter).
- HT Slim Well (not cored, < 6 1/8“ final diameter, up to 2000 m): ~1400 USD/m.
- HT Cored slim well (HQ/NQ, up to 1500 m): ~900 USD/m.
  - Additional cost of up to 30% for deviated drilling and/or balanced drilling.
  - Infrastructure cost not included. The larger the drill rig, the higher the infrastructure cost.
  - For low to intermediate temperature wells the cost can be 25-35% lower.

General analysis of drilling, logging and testing for reservoir information. Which often can also be acquired through slim wells.

- Estimation of formation temperature from:
  - Alteration mineralogy. By microscopic analysis and X-ray.
  - Static formation test. Temperature build-up on bottom for ~6 hr.
  - Various temperature logs.
- Location of productive fractures and permeable zones:
  - Measurement of fluid losses: continuous in flow line, intermittent with tanks.
• Temperature logs.
• Spinner logs.
• From cutting analysis.
• Caliper logs show fracture zones.
• Borehole televiewer / FMI.

• Structure:
• From cutting analysis: lithological logs.
• Hardness from drilling data.

**Drilling data**

- **Geological description:**
  - Stratigraphy
  - Alteration type
  - Intrusion
  - Feed point
  - Remarks

- **Drilling parameters:**
  - Rate of penetration (ROP)
  - Weight on bit (WOB)
  - Circulation loss (L/s)
  - Total weight (t)
  - Pumping (L/s)
  - Pump pressure (bar)
  - Temp. difference (°C)
  - Torque (dNm)
Flow testing of wells

This can be acquired through slim wells

Production test setup (cored well)

Information from short term flow testing

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Output curve, flow rate, static pressure, fluid enthalpy, steam temperature, and formation temperature</td>
<td>Estimated formation temp. from logs</td>
</tr>
<tr>
<td>2</td>
<td>Temperature logs</td>
<td>Static and dynamic logs</td>
</tr>
<tr>
<td>3</td>
<td>Pressure data</td>
<td>Static down-hole pressure, dynamic pressure profile, drawdown during an dth pumping. Water level and bubble point (N)</td>
</tr>
<tr>
<td>4</td>
<td>Chemical data</td>
<td>Consistency of water. Non-condensable gases in steam (HC)</td>
</tr>
<tr>
<td>5</td>
<td>Reservoir data</td>
<td>Conductivity of separated water. Geothermometers - ed. rel. temp.</td>
</tr>
<tr>
<td>6</td>
<td>Optimum production</td>
<td>Self-flowing or pumped. Stability of flow. Optimum operating conditions</td>
</tr>
</tbody>
</table>

Additional information collected during long term flow testing

T&P measurements in a cored well (HQ and NQ)
Data logging of a flow test (from a cored well)

Slim well output curve – example from a cored well
Chemical analysis of samples collected during flow testing of slim well

<table>
<thead>
<tr>
<th>Sampling pressure (bar-g)</th>
<th>2.0-7.5</th>
<th>3.0-8.0</th>
<th>3.5-8.0</th>
<th>3.0-8.0</th>
<th>3.0-8.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sampling temperature (°C)</td>
<td>117.8</td>
<td>137.7</td>
<td>142.6</td>
<td>146.6</td>
<td>146.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Liquid phase, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conductivity (μS/cm/°C)</td>
</tr>
<tr>
<td>CO₂</td>
</tr>
<tr>
<td>H₂S</td>
</tr>
<tr>
<td>SiO₂</td>
</tr>
<tr>
<td>Cl</td>
</tr>
<tr>
<td>Na</td>
</tr>
<tr>
<td>K</td>
</tr>
<tr>
<td>Mg</td>
</tr>
<tr>
<td>Ca</td>
</tr>
<tr>
<td>Al</td>
</tr>
<tr>
<td>Cr</td>
</tr>
<tr>
<td>Mn</td>
</tr>
<tr>
<td>Fe</td>
</tr>
<tr>
<td>Cu</td>
</tr>
<tr>
<td>Zn</td>
</tr>
<tr>
<td>Cd</td>
</tr>
<tr>
<td>Hg</td>
</tr>
<tr>
<td>Pb</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Vapor phase*</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₄ (%)</td>
</tr>
<tr>
<td>H₂ (%)</td>
</tr>
<tr>
<td>Ar+O₂ (%)</td>
</tr>
<tr>
<td>N₂ (%)</td>
</tr>
<tr>
<td>CO₂ (%)</td>
</tr>
<tr>
<td>H₂S (%)</td>
</tr>
</tbody>
</table>

Indian Scenario

Hot springs in India though know since even prehistoric and vedic times, the first attempt to list them was done by Schlaginweit in 1862 when he prepared an inventory of 99 thermal springs. Subsequent workers in GSI added more localities bringing the total to 340 hot springs. The distribution of these springs exhibit the control of three major structural trends in India viz.

i. NW-SE to East-West trending Indo-Eurasian plate margin in Himalayan area.

ii. ENE-WSW trending Intraplate Son-Narmada-Tapi (SONATA) deep seated structural feature.

iii. NNW-SSE deep lineament zone along west coast and NW-SE trending lineament along major river vallies.

Monitoring of Geothermal Resources

A total pf 160 hot springs, hand pumps, public utility bore wells has been monitored since 2013

a. South Region
   1. Manuguru geothermal field, Khammam, Andhra Pradesh.
   2. Aranthangi coastal tract, Pudukkottai district, Tamil Nadu
   3. Irde and Bandaru Hot spring, Dakshina Kannada district, Karnataka.
b. Central Region

1. Unapdeo- Ramtalab-Nazardeo hot springs, Jalgaon, Maharashtra.
2. Sonapdeo, Anakdeo, Ratanpura, Kundwa, Indwa of Maharashtra.
3. Babeha, Pipredi, Maiki block of Shahdol, M.P.
4. Northern-Southern- Central sector of west coast, Maharashtra.

c. Eastern Region

1. Bakreswar manifestation of West Bengal
2. Tantalo Barapalasi and Surajkund manifestation of Jharkhand
3. Athmalik, Atri and Tarabalo, Odisha
4. Rajgir, Bihar.

**Exploration of geothermal energy resources in Pagaderu geothermal manifestation area, Manuguru geothermal field, Khammam (Bhadradri) district, Telangana.**

**Background information**

- The thermal manifestations are emerging through boreholes drilled by GSI and SCCL for coal exploration in and around Pagaderu and the only natural hot spring located at Bugga which is dried out in July 2014.

- The temperature of thermal water recorded was in the order of 35°C to 81°C and the thermal water from hot springs and boreholes can be termed as NaHCO₃ type (Gas enriched meteoric fluid).

- The silica thermometry indicated the temperature ranging from 75°C to 120°C for geothermal system.
Monitoring data of artesian boreholes in Pagaderu area, Telangana.

<table>
<thead>
<tr>
<th>Borehole No.</th>
<th>Temperature(°C)</th>
<th>Locality</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPDW-1</td>
<td>51.0</td>
<td>Pagaderu</td>
</tr>
<tr>
<td>GPDW-2</td>
<td>50.6</td>
<td>Pagaderu</td>
</tr>
<tr>
<td>GPDW-3</td>
<td>63.8</td>
<td>Pagaderu</td>
</tr>
<tr>
<td>GPDW-6</td>
<td>65.6</td>
<td>Pagaderu</td>
</tr>
<tr>
<td>GPDW-6A</td>
<td>81.1</td>
<td>Pagaderu</td>
</tr>
<tr>
<td>GPDW-5</td>
<td>54.1</td>
<td>ST colony</td>
</tr>
<tr>
<td>SCCL-1</td>
<td>41.3</td>
<td>Kodichenkuntla</td>
</tr>
<tr>
<td>SCCL-2</td>
<td>42.6</td>
<td>Kodichenkuntla</td>
</tr>
<tr>
<td>SCCL-3</td>
<td>43.5</td>
<td>Santhi Nagar</td>
</tr>
<tr>
<td>SCCL-5</td>
<td>43.2</td>
<td>Gollakattur</td>
</tr>
<tr>
<td>SCCL-6</td>
<td>54.6</td>
<td>Gollakattur</td>
</tr>
<tr>
<td>GPDE-1</td>
<td>54.1</td>
<td>Gollakattur</td>
</tr>
<tr>
<td>GBC-1</td>
<td>49.9</td>
<td>Bomarajapallium</td>
</tr>
</tbody>
</table>

Location map of the study area, Manuguru geothermal field, Telangana.
Relationship between $\delta^2$H and $\delta^{18}$O of Manuguru geothermal field.

- The $\delta^{18}$O and $\delta^2$H value of the thermal water ranges from -3.5 to 1.83 ‰ and -18.86 to 9.1 ‰ respectively.

- $\delta^2$H- $\delta^{18}$O plot shows that thermal water samples fall along the GMWL indicating their meteoric origin.

- The clustering of all the thermal waters in the same area indicates that same reservoir is feeding the thermal springs. Few thermal spring samples fall on the evaporation line (slope= 4.96) indicating surface evaporation effect. The reservoir sample shows enriched isotopic value due to evaporation occurring in stagnant condition.
Borehole No. MGR-3

- Thermal water of **42.7°C** intersected at **847m** depth in quartzite.
- Thermal water of **52.5°C** intersected at **871m** depth in quartzite.
- Thermal water of **64.7°C** intersected at **891m** depth in quartzite.
Evaluation of geothermal energy resources in Unapdeo-Ramtalab-Nazardeo geothermal manifestation area, Satpura-Tapi geothermal field, Jalgaon District, Maharashtra.

LOCATION MAP

UNAPDEO HOTSPRING

- Dry and now fed by bore well no. UNP/BH/120 by forest department.
- UNP/BH/120 (Temp. 53.2, pH 9.7, EC 0.18)
- The Unapdeo hot spring is located south of the hill slope of the Satpura ranges. Unapdeo hot spring is behind the Unapdeo temple and is channelized to the cemented Gomukh in to cemented tank.
RAMTALAB HOT SPRING

The Ram Talab hot spring is located in the forest land at the foot hills of Satpura. The hot spring is dried since 2014.

Nazardeo Hot Spring

The Nazardeo hot spring is located in Gul River.
During monitoring it is observed that no hot water is discharge from the hot spring and the cemented tank constructed near was filled with river water.

Data of Hot Spring and Public Utility Bore Wells

<table>
<thead>
<tr>
<th>Hot spring area</th>
<th>Temperature (in °C)</th>
<th>EC (μS/cm)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unapdeo</td>
<td>30.0 to 53.5</td>
<td>150 to 310</td>
<td>7.3 to 10.2</td>
</tr>
<tr>
<td>Ramtalab</td>
<td>29.0 to 32.6</td>
<td>310 to 460</td>
<td>7.2 to 7.7</td>
</tr>
<tr>
<td>Bishnapur/Nazardeo</td>
<td>32.6 to 40.0</td>
<td>160 to 290</td>
<td>7.6 to 9.1</td>
</tr>
</tbody>
</table>

Regional isothermal map of thermal water, Unapdeo-Ramtalab-Nazardeo hot spring, Jalgaon, Maharashtra.

The regional isothermal map indicates that, the anomalous temperature is confined to the south eastern part (hot water bore wells). Temperature relief map indicates NW-SE orientation of geothermal manifestation.
The thermal waters from hot springs are rich in Na+K cation and HCO\textsubscript{3} anion. Broadly the thermal water from bore wells can be termed as Na-K-HCO\textsubscript{3} type and the thermal water Unapdeo hot spring can be termed as Na -Cl-SO\textsubscript{4} type (Primary geothermal fluid).

Geological map with BH location and temperature monitored locations in and around Unapdeo-Ramtalab-Nazardeo Satpura-Tapi geothermal field, Jalgaon District, Maharashtra.
BH-04 AND BH-01 along P3 profile of MT survey

BH-01 along P1 profile of MT survey with Core log
PHOTOGRAPHS OF CORE FROM BH: URN-01

0.01 mm to Cm size clasts of sub rounded to sub-angular clasts in carbonate matrix

clasts of basalt, Jasper, zeolites in carbonate rich matrix

Litho logs showing loose silty-clay material near 74m depth

BH-04 & 05 along P4 profile of MT survey and core logs
Networking of carbonate veins along F1, F2 and F3 fractures in greenish-grey colour amygdular basalt at 22m depth

Contact of amygdular basalt and red bole at 91.15m depth

Vesicular basalt, at 92m depth from GL

Massive and amygdular basalt

Fracture zone filled with carbonate clay and silicate mineral, water loss zone.

Fracture with 0.1mm to 0.4mm thick aperture filled with silicate minerals
BOREHOLE: URN-04

Geode with growth of quartz crystals

Mordentite growth in cavities of basalt

Celadonite (green color) in cavities of basalt

Vesicular basalt with partially filled cavities

Heulandite in cavities/vugs of fine grained basalt.

Secondary fillings (amorphous and dendritic shaped) in cavities/vugs of fine grained basalt.

BH-06 and proposed BH 03 & 02 along P6 profile of MT survey
LITHO LOG OF BORE HOLE - URN 06

Soil and rock fragments

Loose silty-sand material with few clasts of basalt and cryptocrystalline silica

Clastic sedimentary rock

184m

Location map of Nandurbar Geothermal Manifestation area, Maharashtra (Part of Toposheet Nos. 46K/2, 46K/5, 46K/6 and 46G/14)
Anakdev Thermal Manifestation

Thermal Manifestation as Seepage
Geological map of Geothermal manifestation AREA Nandurbar district, Maharashtra
(Part of Toposheet Nos. 46K/2, 46K/5, 46K/6 and 46G/14)

Northern sector
Koknere, Haloli, Paduspada, Sativli, Akloli & Ganeshpuri.

Central Sector
Sov, Vadavli, Pali and Unhavre (Tamhane)

Southern sector
Khed, Unhavre (Khed) Aravli, Tural, Rajawadi Sangameshwar, Math and Rajapur.
The proved reserve of geothermal energy in Tattapani geothermal area is 10 MW power generation for 20 years period based on drilling up to 500 to 600m.
Calculated by Dr. P.B. Sarolkar Dy.DG (Retd) and GSI team
Geyser of Exploratory Borehole No. Gw/Tat/23 During 4th September’13

Showing gases emission with strong smell of sulphur
IGA- Representing the Geothermal Sector
Varun Chandrasekhar
Director - GeoSyndicate Power P Ltd

International Geothermal Association

• Scientific, educational and cultural organization with 5,000+ members in over 65 countries.
• Non-political, non-profit, non-governmental organization with consultative status to the UN and special observer status to the Green Climate Fund – Partner to the Global Geothermal Alliance
• Founded in 1988, IGA Secretariat is located in Bochum, Germany at the International Geothermal Centre of the Bochum University of Applied Sciences.

International Geothermal Association
• Objectives:
  - Encouraging research & development and utilization of geothermal resources as a whole worldwide through the publication of scientific and technical information among the geothermal specialists, the business community, governmental representatives, UN organizations, civil society and the general public.
  - Encourage, facilitate and, promote the coordination of activities related to worldwide research, development and application of geothermal resources.
  - Assist Government and stakeholders on drafting and implementing policy framework
  - Handholding stakeholders at different levels.
The IGA Academy

- The IGA Academy is an institution of the International Geothermal Association (IGA) with the aim of promoting international education and training in the geothermal energy sector. Certification is carried out by the IGA and the accredited partner institutions. The contents of training courses include the following topics, which are initially offered in 1-week or 2-week courses:
  - Drilling technologies for geothermal wells
  - District heating systems
  - Geothermal heat pump technologies
  - Power plant technologies (low, medium and high temperature)
  - Reservoir Engineering & Reservoir Modeling
  - Hydrochemistry / Geochemistry
  - Numeric modeling for heat and fluid transfer
  - Project management and financing
  - Regulatory framework conditions
  - 3 level drilling course (for example W120 standard)
  - (Enhanced) Geothermal Response Tests
  - Power plant technologies (high temperature or binary)
  - Reservoir development and reservoir monitoring

IGA Service GmbH

- The IGA Service GmbH is a limited liability company with headquarters in Bochum, Germany. The company is registered with the Bochum Local Court under the Commercial Register number HR B 13504. IGA Service GmbH was founded in 2009 in Germany and is owned by the International Geothermal Association (IGA). The main objectives are the promotion of geothermal energy and its application, sharing of sector-specific knowledge, research, event organisation, consulting tasks and others as required.
• Personnel: The exceptional IGA network of global geothermal experts, regional IGA branches and IGA representations through Board members in the leading geothermal countries greatly support the IGA Service GmbH in conducting their tasks.

• Partners: Previous project partners/contractors include the International Renewable Energy Agency (IRENA), the International Finance Cooperation (IFC), the International Labour Organisation (ILO), the World Bank (WB) and others.

IGA Regional Branches
• European Branch Forum
• East Africa Regional Branch
• Asia-Western Pacific

Top 10 Geothermal Countries Installed capacity (MW) Jan. 2018 Total 14,060 MW January 2018

<table>
<thead>
<tr>
<th>Country</th>
<th>Installed capacity (MW)</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>3,591</td>
<td></td>
</tr>
<tr>
<td>Indonesia</td>
<td>1,868</td>
<td></td>
</tr>
<tr>
<td>New Zealand</td>
<td>1,809</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>1,100</td>
<td></td>
</tr>
<tr>
<td>New Zealand</td>
<td>980</td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>951</td>
<td></td>
</tr>
<tr>
<td>Kenya</td>
<td>944</td>
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<tr>
<td>Other</td>
<td>889</td>
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<tr>
<td>Other</td>
<td>710</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>676</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>542</td>
<td></td>
</tr>
</tbody>
</table>
Geothermal – energy beyond electricity

Selected

Geothermal Direct Use Applications

- **Heating**
  - Beijing, China

- **Fish Farming**
  - Salton Sea, California

- **Greenhouses**
  - Olkaria, Kenya

- **Bathing/spa**
  - Jigokudani Monkey Park, Japan

- **Minerals**
  - Salton Sea, California

- **Street Heating**
  - Reykjavik, Iceland
Energy Demand European Union 2013 Final Demand by Sector in EUR28: 14,000 TWh
The following key issues were discussed in the round table:

1. What are the 1-2 biggest barriers to government of India deciding to go with Geothermal?

2. How risk is going to be shared between public and private actors – and specifically the role of government in de-risking geothermal development opportunities and increasing their bankability?

3. Can speculative surveys be done by Government which helps in preparing data docket for auctioning

4. Does steam classification happen in India for various geothermal provinces?

5. What time frame is required for catering need of potential users with proper analysis of saleability and bankability?
Multipurpose and cascade use of geothermal energy

Gunnar Ingi Gunnarsson
Chairman of the Board of Verkís

Verkís Consulting Engineers

- Verkís was formed 2008 by merging of five consulting companies and 2013 one more joint the company.

- Over 300 employees

- Turnover 2017: Around 50 mUSD

- Dated back to 1932, being the oldest engineering company in Iceland.

Projects worldwide
Services
• Project Management
• Project control, risk and cost assessment and planning
• Feasibility studies and conceptual design
• Design - Sketch phase, pilot projects
• Assessment of environmental impacts
• Purchasing
• Management of construction
• Health, safety and environment
• Testing and approval

Expertise
• Civil Engineering
• Electrical system
• Control Systems
• Lighting
• Ventilation
• Acoustics
• Fire and Safety design
• Mechanical Engineering
• Geotechnical design
• Road and transport design
• Environmental
• Project Management
• Construction supervision
• Health and Safety

Geothermal utilization

![Diagram of geothermal utilization](image-url)
**Organic Rankine Cycle**

**Single stage binary cycle**

![Organic Rankine Cycle Diagram](image)

**Cost breakdown ORC projects**

*Typical investment cost* ¹)

**pr. MW electrical:**

**USD 4.0 to 8.0 million (Binary)**

1) *Based on mean well output of 3 MWe*

*Typical drilling cost*

**pr. 2500 m well:**

**USD 4.0 to 7.0 million**

**Main benefits**

An Organic Rankine Cycle can be a viable choice:

- If the geothermal fluid has relatively low temperature
- If the geothermal steam is not suitable for use in turbines
- As bottoming units, thus utilizing geothermal brine for power production
• 100% reinjection possible by using ACC (Air cooled condenser)

**Industry**

**Industrial applications**

• Drying - The most common operation
• Process heating – preheating of boiler water etc.
• Evaporation – extraction of salt and other minerals
• Washing
• Refrigeration – absorption freezing and cooling
• CO₂ production for greenhouses use
• Methanol production from CO₂
• Cosmetic (Blue Lagoon)
• Food supplement (Geosilica)
• Industrial application tend to have high load factors (0.4 - 0.7) which reduce the unit cost of energy
Production of methanol in Svartsengi

Food / fish processing

- Fish farming
- Fish drying
- Fish cooling/ freezing
Heating – Cooling

Space heating – main characteristics

• Space and district heating is among the most successful geothermal direct applications in countries with cold climate

• Preferred water temperature is in the range 60-90°C. Common return water temperature is 25-40°C

• Chemical composition of the water is important

• Radiators or floor heating systems are commonly used. Air heating systems are also possible.

• Geothermal heat pump can be used if the temperature of the resource is too low for direct application
Conclusion for snow melting

• Reliable system

• Low operational cost

• Better Environment

• Fewer Accidents

• Reduced use of salt and sand

• Cleaner floors of buildings
Pilot Cogeneration Plant for Puga Geothermal Field, India

Kunzes Dolma
Senior Project Engineer, LREDA-LAHDC

Experience in Iceland

• Lifetime opportunity for a person and that too a woman from a small corner of the world which remains cut off for 6 months.

• Hope to be a motivation for more woman to come out of the comfort zones

• Energy access can uplift living standards.

What is the report about?

• Design of a pilot binary power plant and heating system

Current situation:

• Electricity is only available for these students through a 10kVA diesel generator from 5pm to 11pm
Main source of heating for the seven months is wood and kerosene.

**Purpose of the project**

- To provide 24 hour electricity.
- To provide comfortable room temperature of 20°C
  - Even when the outside temp is below -25°Celcius.

**So what is the project?**

- Design cogeneration of electricity and heating for the school from the available geothermal fluid
- The expected flow (12 kg/s) is sufficient to have the ORC plant and the school heating system in parallel
- The available fluid will have around 84°C temperature at the source
- The power plant should be able to start without having any electricity available (Black Start)

**How are the possible power plants?**

- The geothermal fluid may come from a well under (low) pressure
  - The ORC plant is then made with conventional shell and tube heat exchangers
  - The well pressure has to be sufficient to force sufficient fluid through the plant heat exchangers in order to start the plant
- It is also possible that the flow is surface flow from a natural spring
  - A “swimming pool” is then used for the geothermal fluid and heat exchangers with the working fluid on the tube side are “dipped” into the pool.
The “swimming pool” design

Selected power plant

- A conventional ORC system with shell and tube heat exchangers was selected
- It is likely that the wells will have sufficient pressure so that the plant can be started without any pump running
- R134a was selected as working fluid
  - The tested working fluids showed similar performance, except Propane (which had less power)

Return temperature and net power
ORC plant at 5°C air temperature

Building

Chart Title

Heat Loss from the Floor
Effect of insulation on building heating demand

<table>
<thead>
<tr>
<th>Insulation criteria</th>
<th>Typical demand (kWh/year)</th>
<th>Glazing type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Insignificant insulation</td>
<td>&gt;100000</td>
<td>Single</td>
</tr>
<tr>
<td>Poor insulation</td>
<td>55300</td>
<td>Single</td>
</tr>
<tr>
<td>Icelandic building code</td>
<td>30000</td>
<td>Double</td>
</tr>
<tr>
<td>Swedish building code</td>
<td>26800</td>
<td>Triple</td>
</tr>
<tr>
<td>Super insulation</td>
<td>22500</td>
<td>Quadruple</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Heat loss for each rooms</th>
<th>With insulation</th>
<th>Without insulation</th>
<th>Radiator model</th>
<th>No of radiator</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Room 1g</td>
<td>2050</td>
<td>4870</td>
<td>33-PKKPKP 900</td>
<td>1</td>
<td>3.00</td>
</tr>
<tr>
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<td>2317</td>
<td>5456</td>
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</tr>
<tr>
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<td>9262</td>
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<tr>
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<td>9156</td>
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<td>5378</td>
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<tr>
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<td>6542</td>
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<td>11443</td>
<td>38145</td>
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<td>3.00</td>
</tr>
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<td>Room 10g (kitchen)</td>
<td>1884</td>
<td>6304</td>
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<td>33-PKKPKP 600</td>
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<td>2.00</td>
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<tr>
<td>Corridor first floor</td>
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<td>32947</td>
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<td>Total Heat loss</td>
<td>73899</td>
<td>203357</td>
<td></td>
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</tr>
</tbody>
</table>

Building heating system
Why geothermal development is crucial

- India started geothermal exploration in Puga in early 1970s and later China followed but China has, since 1976, been operating a 25 megawatt plant in Yangbaijan, Tibet, exploiting geothermal water at a temperature of 160 degrees.

- As per a report of 2013 three million litres of diesel is burnt annually in the region at a cost of approximately US$ 2 million for electricity generation.

- Extensive use of wood, cow dung, kerosene, coal for heating.

Visual Impacts of Climate Change

- Flash flood of 2010: loss of 255 human lives, damaged crops, killed livestock, bridges, houses washed away, roads cut off, snapped telecommunication for months,

- Flash flood of 2015: damaged crops, properties

- Changes in precipitation patterns

- Glacial Lake Outburst Flood (GLOF)
**Benefit of developing geothermal energy to people**

- 24 hour electricity.
- Cascading use for heating, recreational activities (swimming), aquaculture, cold storage greenhouses etc can generate employment (around 3% of the 1,40,000 people are unemployed).
- Better health conditions due to smoke free houses.
- Many small scale industries like carpentry, weaving will start.

Cashmere: the authentic cashmere wool are from the Pashmina goat living in the uplands of Ladakh.

To fulfil India’s goal in combating Climate change/ global warming along with achieving Sustainable Development Goal 7 which ensures access to affordable, reliable, sustainable and modern energy for all.

**Climate Change Mitigation: LREDA-LAHDC efforts**

- Solar photo voltaics
- Solar water heaters
- Solar Steam Cooking Systems
- Solar Dish Cooker
- Solar Greenhouses
- Solar Passive Architecture
- Ban of plastic bags since 1998
Integrated Energy Approach for Solar -Geothermal (SGT) Development in India

Sagarkumar M. Agrawat
Head R&D, GERMI

Outline of Presentation

- Case – study of GERMI 150 TR Solar Thermal AC System
- Typical Financials of Solar Thermal AC System
- Pros & Cons of Solar Thermal System
- Advantages and Limitations of Geothermal System
- Integrated cycle for solar-geothermal heating / cooling applications
- Integrated cycle for solar-geothermal-coal (thermal) system for power generation
- Advantages of integration and
- Future scope of work

Schematics of GERMI’s 150 TR Solar Thermal AC Pilot
Technical Brief

**Highlights of 150 TR Solar Thermal AC project, GTPS:**

1. ETC – CPC Type Solar Thermal Collectors: 525 Nos. (Aperture Area of each collector: 3 $m^2$) $\eta = 64\%$

2. Vapour Absorption Machine (VAM): 150 TR CoP : 0.71

3. Air Handling Unit (AHU): 3 Nos. Capacity : 50 TR each

4. Hot Water Storage Tank: 30,000 Litre Capacity

5. Electrical Panels: 3 Nos. (MCC, Heater, PLC)

6. BoS: Twin Cell Cooling Tower, PHE, Pumps, Piping & its accessories, Data Logging Sensors & SCADA system, electrical cables and heaters

**Storage and control system**

**Electrical Panels and VAM**
Financial Analysis of CST based AC System

CUF = 24.5%

Electricity Cost =

Case i) INR 7 / kWh (Grid Electricity);
Case ii) INR 10 / kWh (Grid + Diesel 20%)
Case iii) INR 18 / kWh (Diesel)

Payback Period (Best Case Scenario i.e. Case iii)) Annual Savings are INR 29.3 Million offering payback of 1 Year 5 Months
Payback Period (Worst Case Scenario i.e. Case i) Annual Savings are INR 11.2 Million offering payback of 4 Year 3 Months

Pros and Cons of Solar Thermal AC System

Pros:

1. Simplicity of design and operation
2. Possibility of energy storage for non-sunny hours operation
3. Round the clock true (heating / cooling / dehumidification) air-conditioning
4. Green / clean technology
5. Matching with demand curve i.e. chilling capacity increases with increase in cooling load
6. More efficient to PV system

7. Can be installed anywhere with good solar radiation

8. Available with variety of options i.e. point focussing, line focussing, non-imaging collectors etc. for different temperature ranges

**Cons:**

1. Operation in non-sunny hour requires storage

2. Varying capacity due to varying solar radiation

3. Requires electricity to operate pumps and other machineries

4. Possibility of manufacturing in India

**Ideal Solution for Hybridization with Geothermal Sources for Heating / Cooling or Power Generation**

**Advantages and Limitations of Geothermal System**

**Pros:**

1. Can work with very low temperature to high temperature

2. Availability of energy round the clock (24 x 7)

3. Complements solar cycle i.e. differential temperature is more when air temperature is lower

4. Requires lower foot-print on ground

5. Heat pumps are very much popular and proven application

6. Geothermal power generation plants are very much reliable and proven

7. Ideally suitable for remote and hilly regions of India

8. Ability to operate as stand-alone system

**Cons:**

1. Lack of local market

2. Higher capital Investment

3. Location specific

4. Requires continuous maintenance
5. Potential of geothermal system is yet to be confirmed

6. Requires environmental assessment

Resource Map of India

CST – Geothermal Combined Cycle for Low Temperature Geothermal Resources
Advantages of Integration

1. Universal design for any temperature range
2. Increased reliability
3. Improved system efficiency
4. Improved economics
5. Stand-alone design for rural / remote areas

Future Scope of Work

1. Pilot demonstration project of integrated solar and geothermal combined cycle for heating / cooling / power generation is required to establish techno-commercial viability of the system
2. Potential of integrated solar and geothermal combined cycle operation with thermal power plant to offer grid-balancing (storage) is required
3. Economic analysis needs to be undertaken
4. Market development through multiple demonstration projects for variety of applications is required

5. Suitable viability gap funding with competitive bidding is required
CEGE TEAM FALICITATION

Mr. Shishir Chandra
Convenor 3rd International Conference on Geothermal Energy, 2018

Mr. Dwijen Vaidya
Coordinator 3rd International Conference on Geothermal Energy, 2018

Mr. Manan Shah
Public Relation Officer 3rd International Conference on Geothermal Energy, 2018

Ms. Kriti Yadav
Logistics Head 3rd International Conference on Geothermal Energy, 2018

Ms. Namrata Bist
Organizer 3rd International Conference on Geothermal Energy, 2018

Mr. Hari Ganesh
Organizer 3rd International Conference on Geothermal Energy, 2018
CEGE IN SOCIAL MEDIA

TWEET’S

1. Thorir Ibsen: At the end of an excellent International Conference on Geothermal Energy organised by the Centre of Excellence for Geothermal Energy (CEGE) in Gujarat in affiliation with the Embassy of Iceland to India.

2. Iceland in India: Mr Ólafur Flovenz CEO of Iceland GeoSurvey (ISOR) and Prof. Anirbíd Sircar Head of the Centre of Excellence for Geothermal Energy (CEGE) signing a Memorandum of Understanding on geothermal cooperation at the Int Conf on Geothermal Energy in Gujarat.

3. Iceland in India: Experience shows that strong political commitment and initial public support is required to reap the long term economic, social and environmental benefits of geothermal energy, said Ambassador Thorir Ibsen in his opening speech of the 3rd Int Conf on Geothermal Energy in Gujarat.

4. Iceland in India: Ólafur Flovenz CEO of Iceland GeoSurvey (ISOR) speaking about how geothermal energy contributed to increasing the share of renewable energy to the point of supplying close to 90% of primary energy consumption in Iceland.

5. Iceland in India: Gunnar Ingi Gunnarsson, CoB of Verkis speaking about the multiple uses of geothermal in addition to electricity production, including space heating and cooling, food processing, greenhouses, aquaculture, tourism and spas, industrial applications, food supplements & cosmetics.

6. Iceland in India: Ingimar Haraldsson Deputy Director of the UNU Geothermal Training Programme in Iceland, said that 670 experts from 60 countries have graduated from the programme.
Embassy of #Iceland in New Delhi in partnership with the Centre of Excellence for Geothermal Energy (CEGE), Pandit Deendayal Petroleum University (PDPU) organised the 3rd International Conference on Geothermal Energy, held on 17 January 2018 in Gandhinagar, Gujarat.

Bjarni Richter, Director Iceland GeoSurvey (ISOR) presenting new technologies being developed in Iceland to reduce costs of exploration drilling for geothermal water.
CONFERENCE
GLIMPSE