RG Thermal Energy Solutions

Geothermal Energy: An Option for Oman?

The overlooked potential of low-temperature geothermal resources

AMBATA
CAPITAL PARTNERS

- Experts in financing the development of clean energy in the Middle East & Africa
- Ambata matches top technologies from around the world with regional opportunities in clean energy and sustainability
- Growing portfolio of cleantech companies & solutions in the Middle East, covering off-grid power, efficient building technologies, efficient agriculture, etc.

RG
Thermal Energy Solutions

- *Founded by Ambata & Reykjavik Geothermal*
- *RG Thermal Energy Solutions (RG-TES) is a low-enthalpy geothermal consulting & development company*
- *RG-TES is focused on developing geothermal desalination, cooling, and steam generation projects in the Middle East & Africa*

RG
Reykjavík Geothermal

- Unparalleled experience in geothermal development and operation
- Former management team of the world's largest geothermal-powered utility
- Pioneering technical expertise in the application of geothermal energy around the world
- Focused on the development of geothermal power in emerging markets

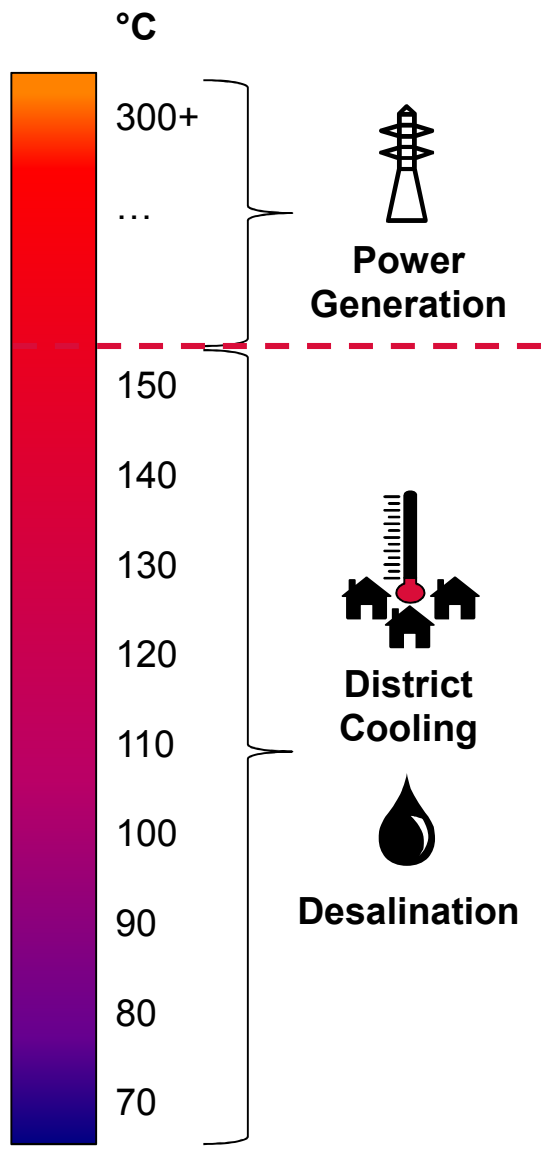
RG Reykjavík Geothermal

- Reykjavik Geothermal is a leading geothermal power development company, which develops high temperature geothermal resources into geothermal power plants globally

RG Thermal Energy Solutions

- **The Middle East is a unique geothermal market:**
  - **Resource are plentiful but of lower temperatures, unsuitable for power generation**
  - **Direct thermal energy applications are plentiful, especially desalination and cooling**

- **RG-TES is a Dubai-based geothermal energy company, focused on the development of low enthalpy geothermal resources for desalination, cooling, and steam production in the Middle East & Africa**



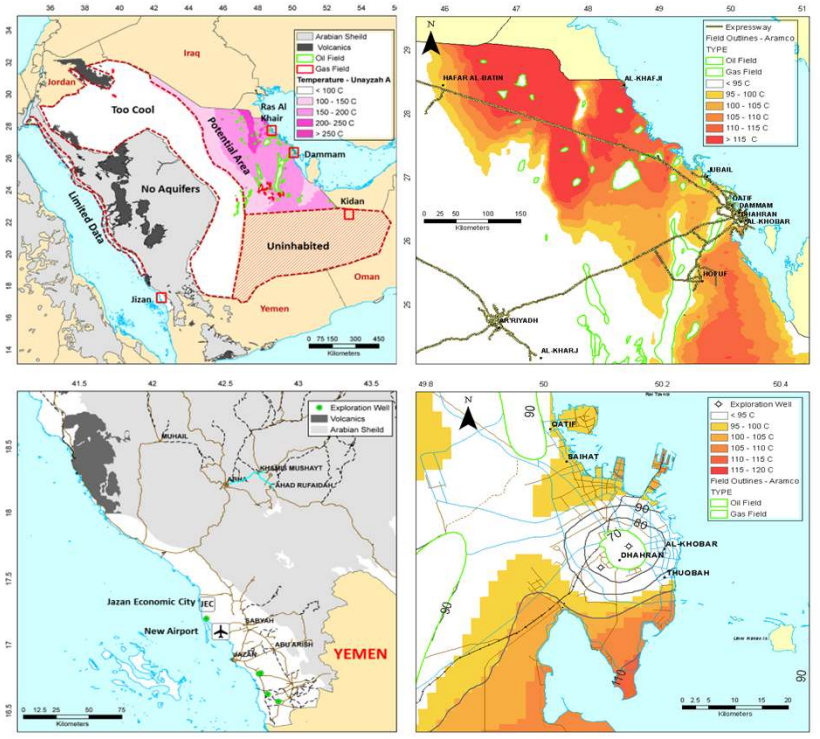
RG-TES Case Study #1: Geothermal wells for Masdar City

- RG drilled the first low-enthalpy geothermal project in the Middle East at Masdar City (UAE) in 2010.
- Project consists of a closed loop of 2 geothermal wells, with a flow rate of 100 kg/sec, and an average temperature of 95°C.
- The geothermal wells are to be used for district cooling for the Masdar City development

Left to Right: Icelandic President Ólafur Grímsson & Masdar City CEO Dr. Sultan Al Jaber, Masdar well drilling, Site visit by Dr. Sultan Al Jaber

RG-TES Case Study #2: Resource assessment for Saudi Arabia

- The RG-TES team & RG geoscientists were tasked with geothermal resource assessment for Saudi Aramco.
- The team's findings have shown that the geothermal resource in the region is much greater than previously estimated
- Work continues on the project with the overall aim of developing 2-3 geothermal cooling & desalination plants.

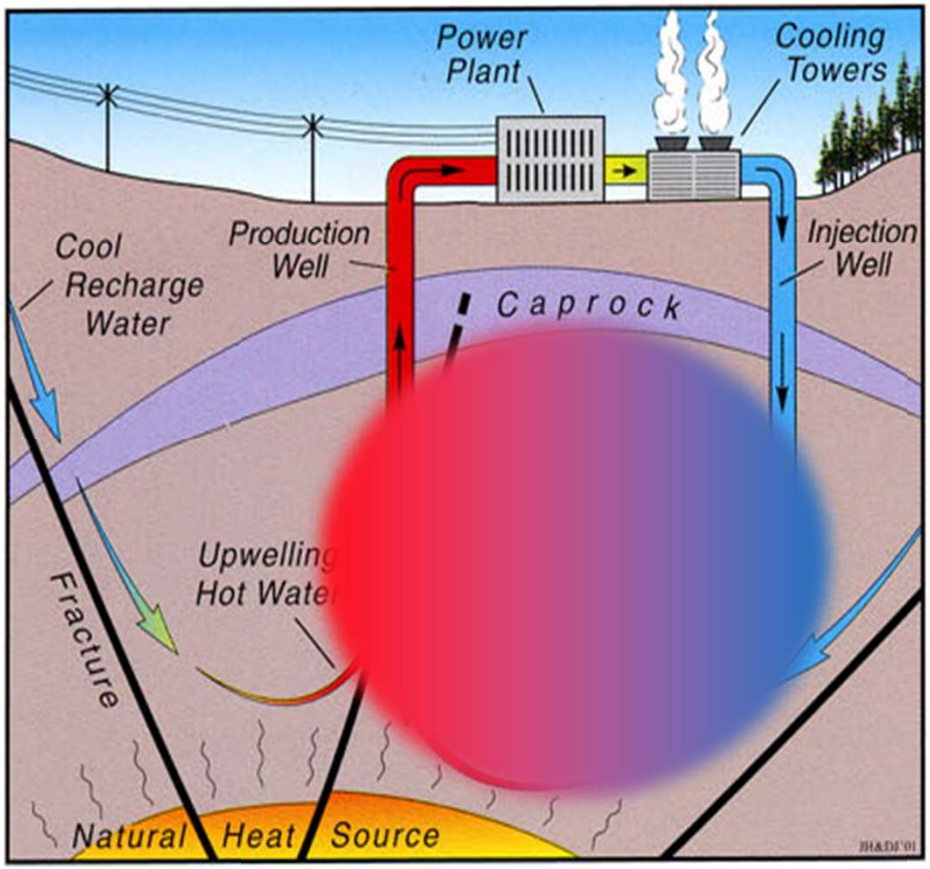


Geothermal resource maps of Saudi Arabia (RG)

Agenda

1. Geothermal overview
2. Does geothermal energy work in the Middle East?
3. Applications in the Middle East
4. Conclusions

What is geothermal energy?



Geothermal Resources can be divided into two types based on the temperatures of the geothermal reservoir:

Medium/High-Enthalpy Resources

- Reservoir temperatures of 150-300+°C
- Ideal for conversion to power
- Typically only found in volcanic regions

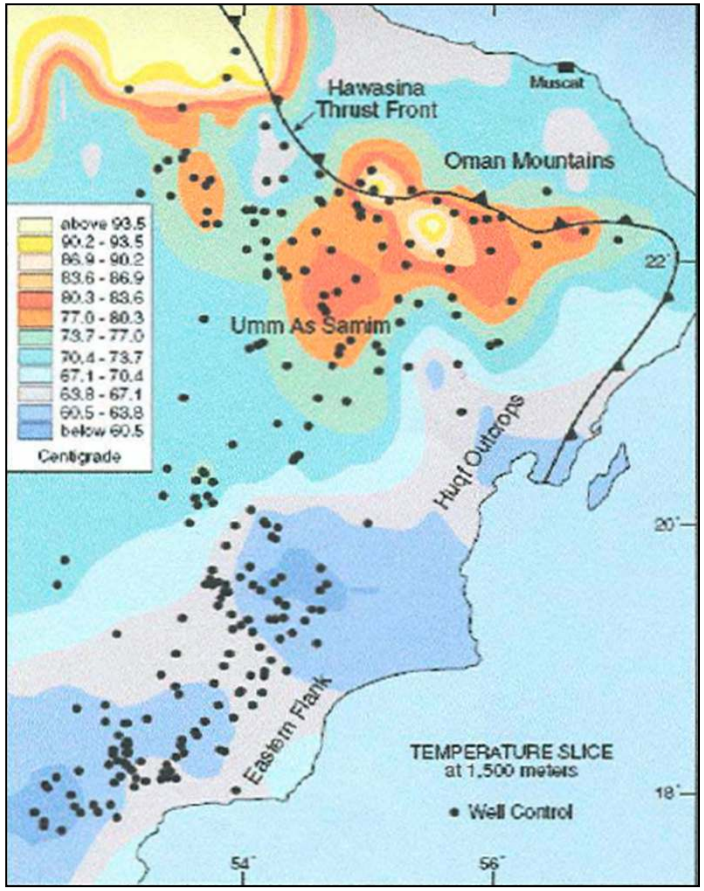
Low-Enthalpy Resources

- Reservoir temperatures of 90-150°C
- Far more common
- Ideal for direct applications, i.e. heating, cooling, desalination & steam generation

Common in the Middle East

The potential for low-enthalpy geothermal energy in Oman appears to be significant

Geothermal resources in Oman (1,500 m)

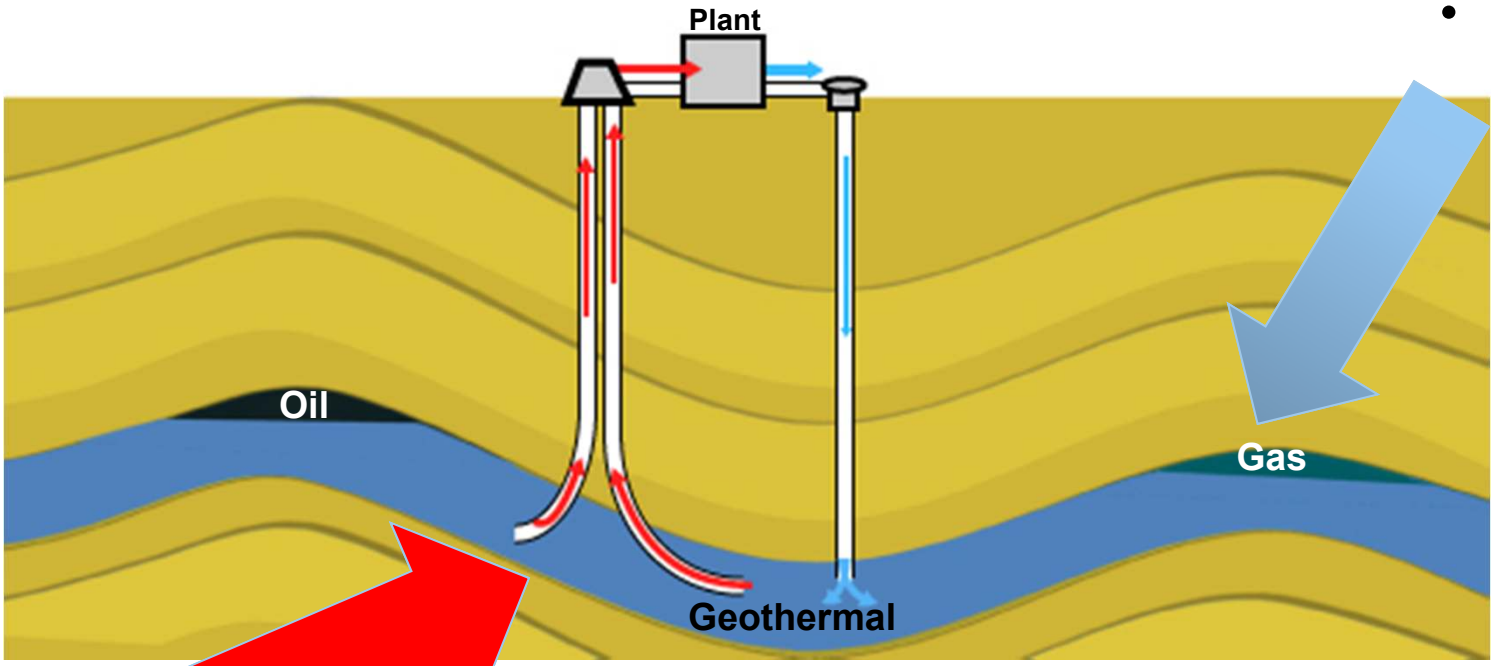


Source: Al Lamki & Terken, GeoArabia, Vol.I, no.4, 1996

Low-enthalpy geothermal resources – where to look

Anticlines

- host oil & gas traps

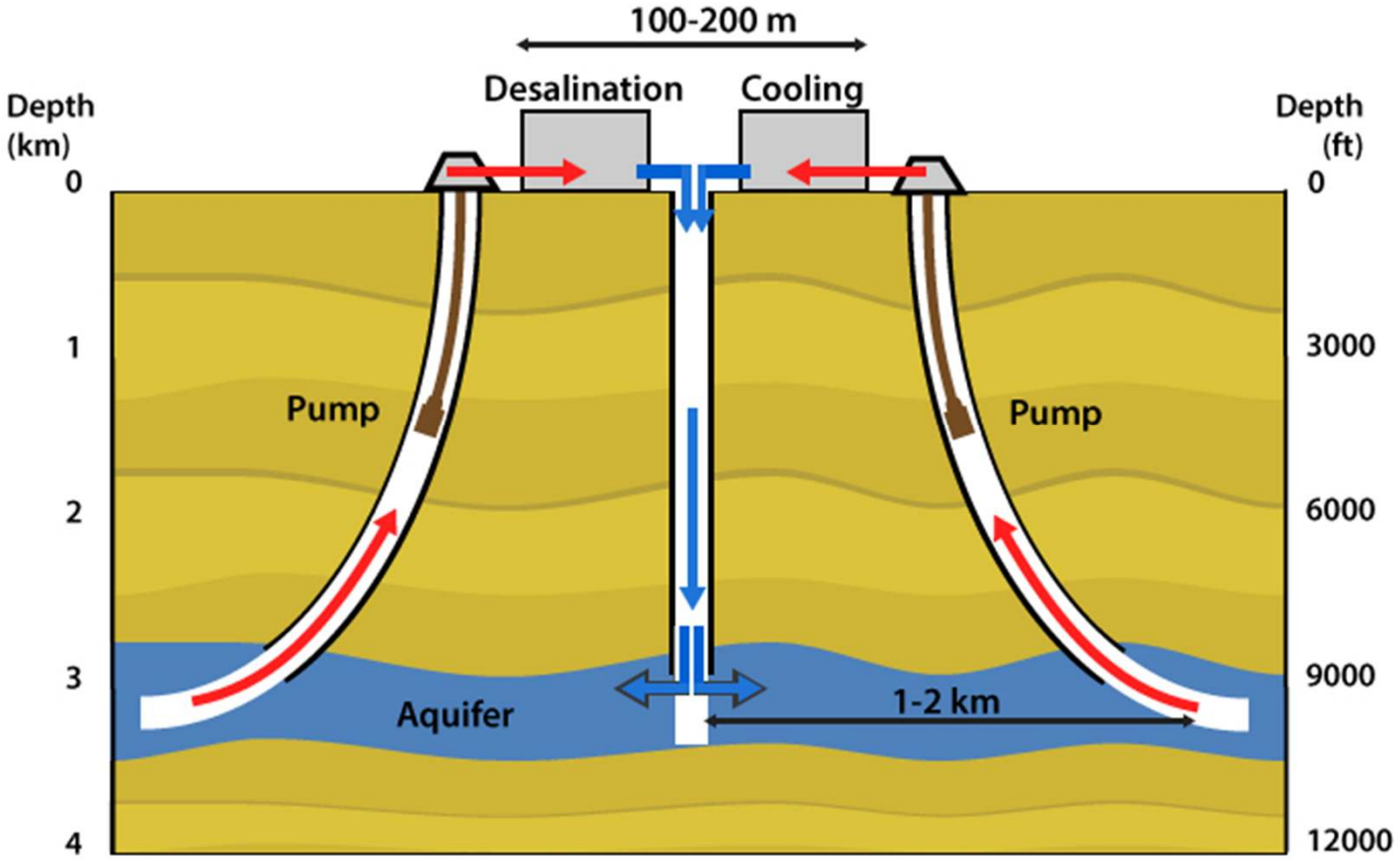


Synclines

- Are aquifers filled with water = geothermal resource
- They are deeper and hotter

Geothermal energy is typically accessed through a 'triplet' closed-loop well configuration

Typical Geothermal Well "Triplet"
2 production + 1 re-injection well



1 production well / km² yields roughly 100 kg / second / km²

or roughly

10 $MW_{thermal}$

Geothermal has the highest ratio of energy density to physical footprint of all renewables

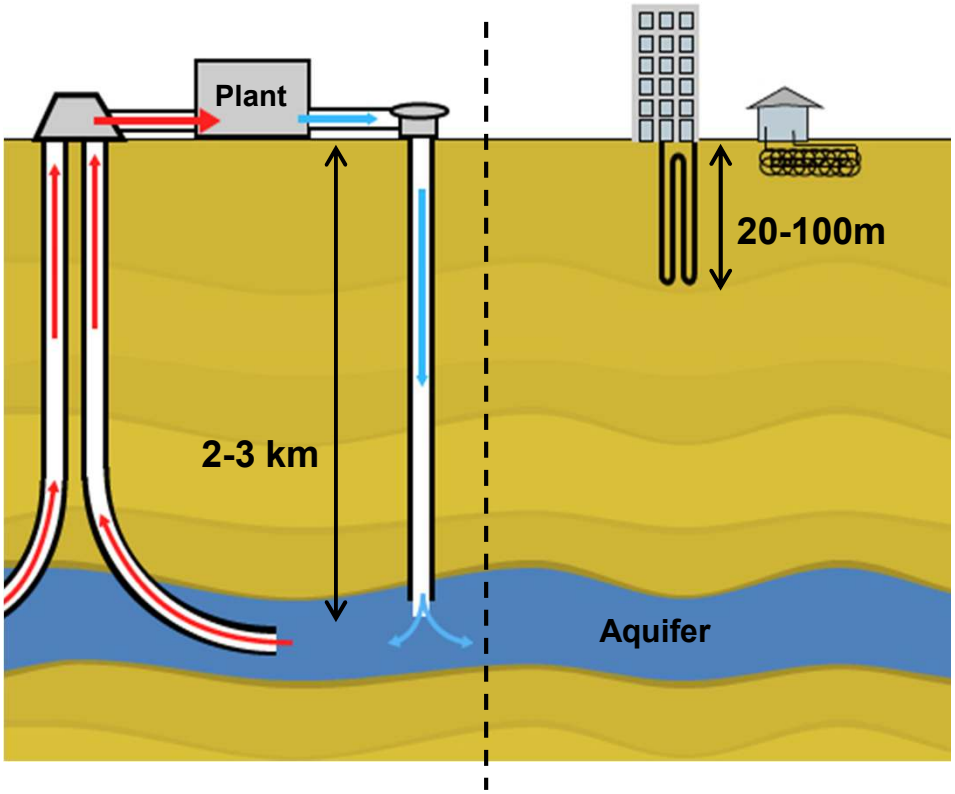
Well Drilling ~100 * 150 m

Completed wells ~ 5 * 5 m

Low-enthalpy geothermal energy is different than ground source heat pumps

Low-enthalpy Geothermal Wells

- Drilled to a depth of 2-3 kilometers
- Heat is extracted from deep aquifers heated by the earth's core
- Produces useful temperatures up to 150°C
- Applications:
  - Desalination
  - District cooling
  - Steam generation



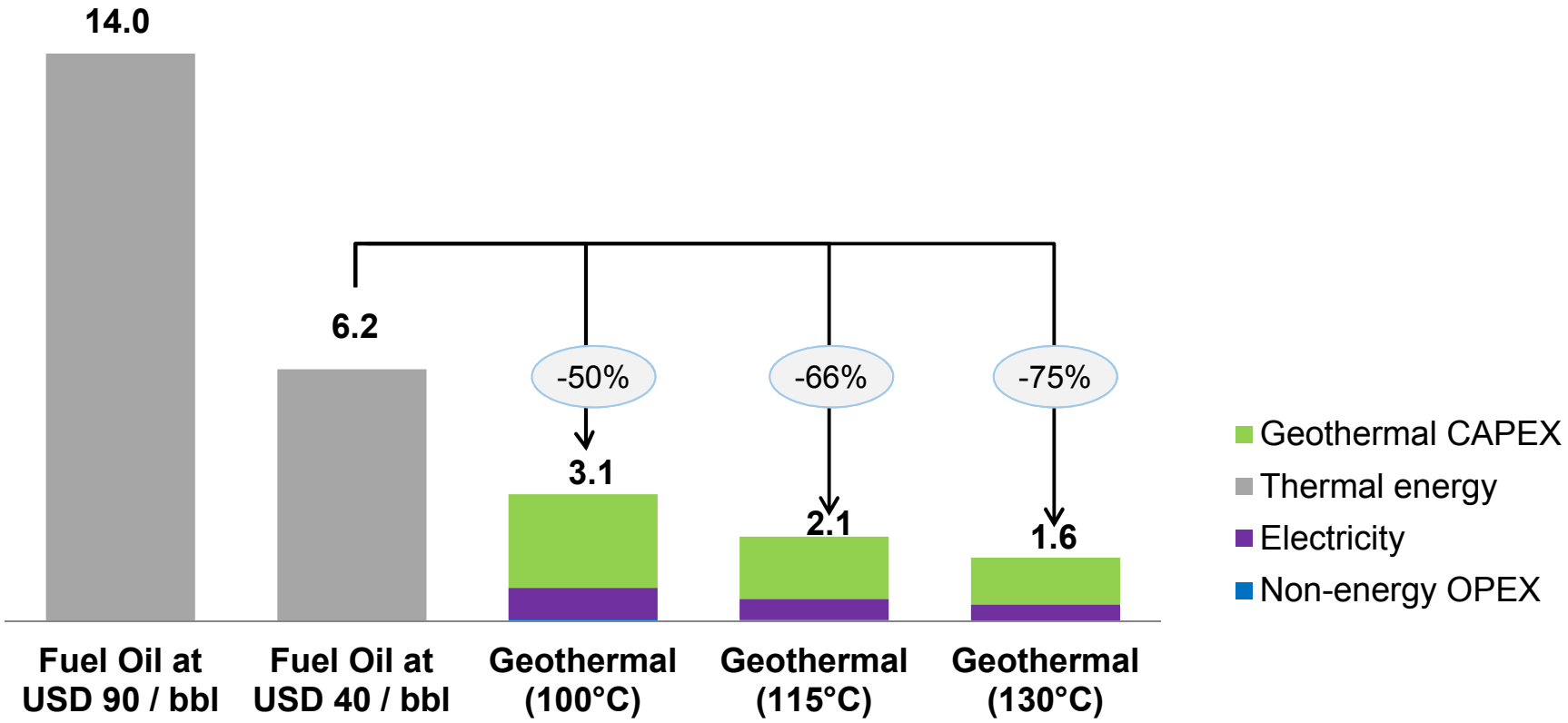
Ground source heat pumps

- Closed loops are buried to a depth of 20-100 meters
- Heat is stored in the top layer of earth during summer, and recovered in winter
- Produces useful temperatures of up to 60°C
- Applications:
  - Space heating & cooling

Low-enthalpy geothermal heat is cheap, making it very interesting for various direct use applications

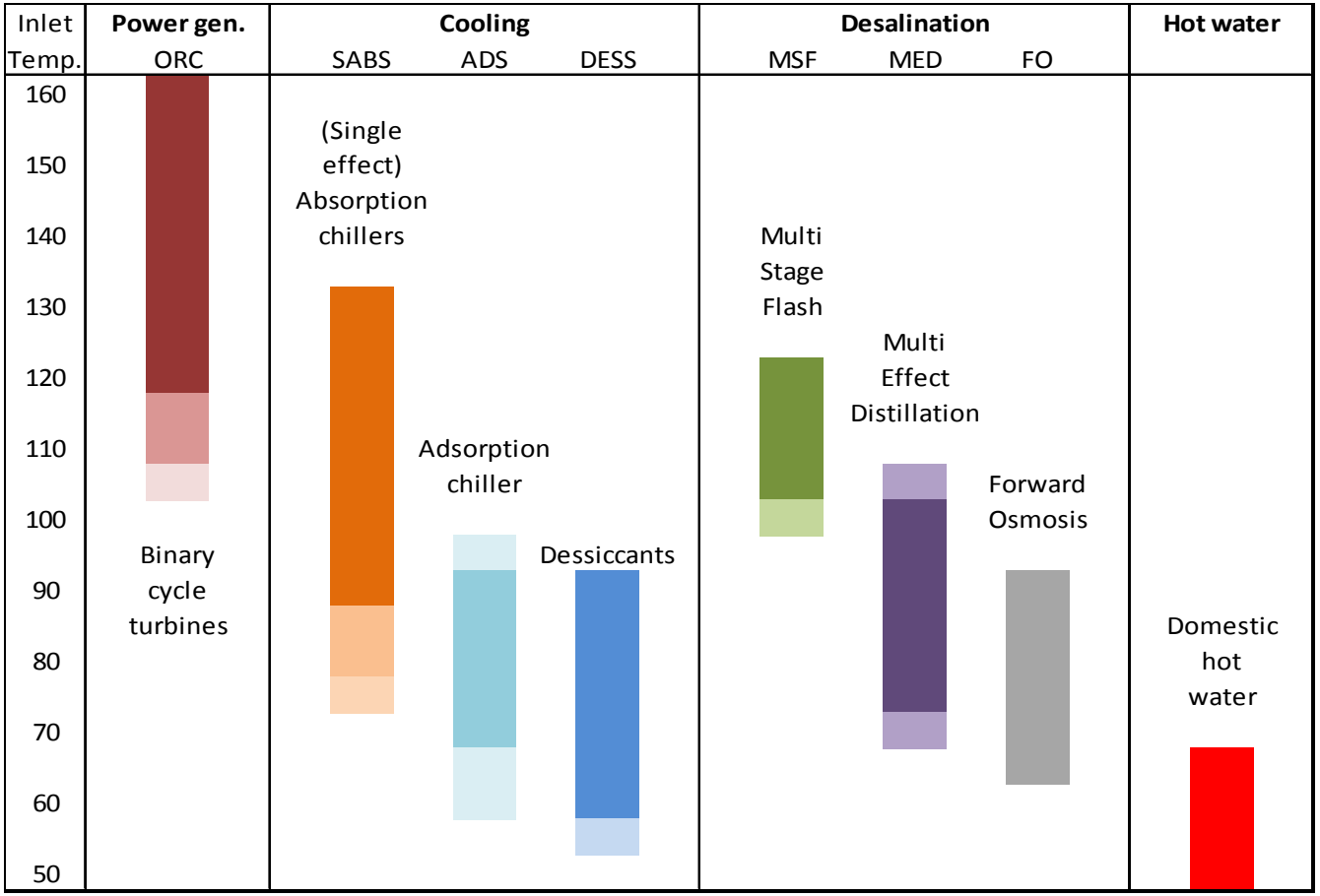
Levelized Costs of Low-enthalpy Geothermal Heat

For heat use down to ambient (35°C), in USD / mmBTU (electricity price of USD 0.12 / kWh_{el})



The most relevant regional uses for low-enthalpy energy are cooling, desalination and hot water/steam generation

Applications for Low-Enthalpy Geothermal Energy in the Middle East

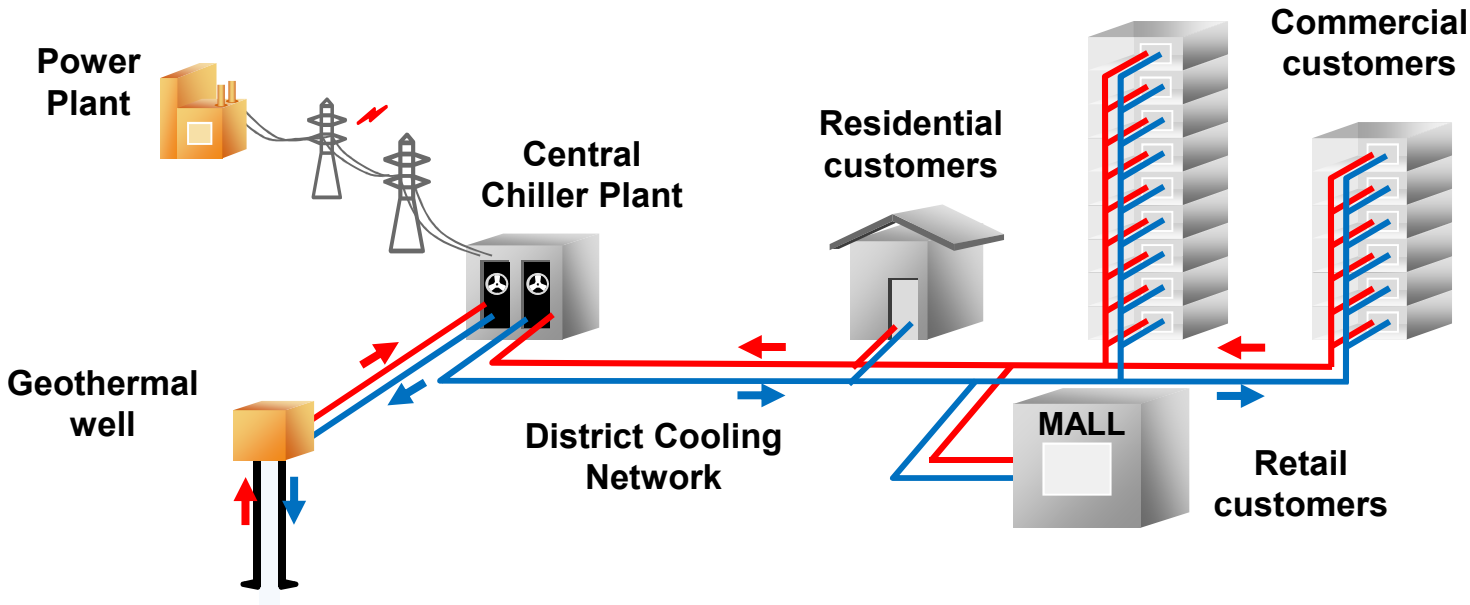


Cooling accounts for 40-50% of electricity consumption in the GCC

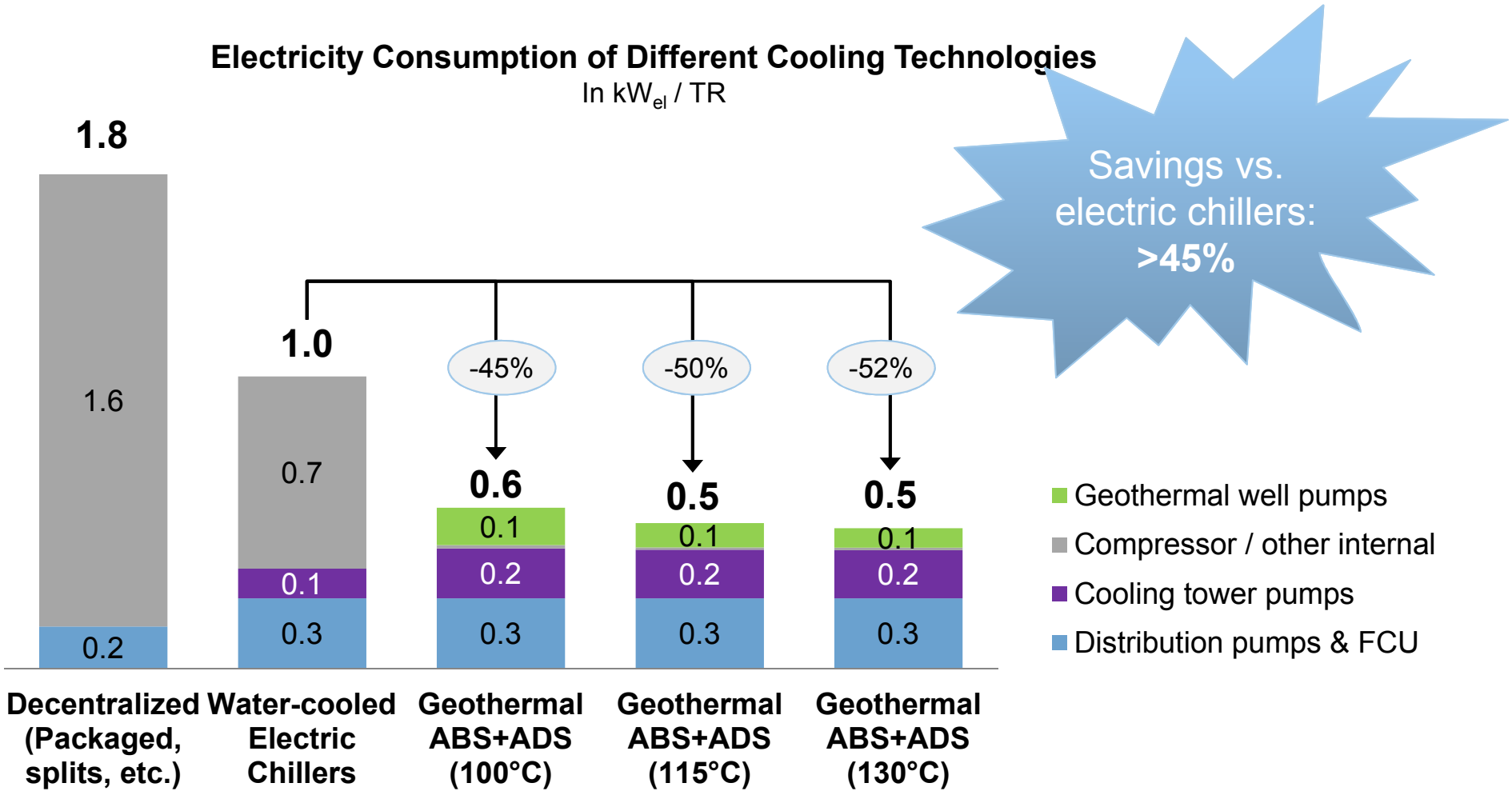
Desalination accounts for 10-20% of energy consumption in the utility sector in the GCC

Adding geothermal capacity to district cooling systems requires adding some thermal chiller capacity to the central plant

District Cooling System in the Middle East with Geothermal Energy
Baseline



There are significant savings in energy consumption when using geothermal for cooling

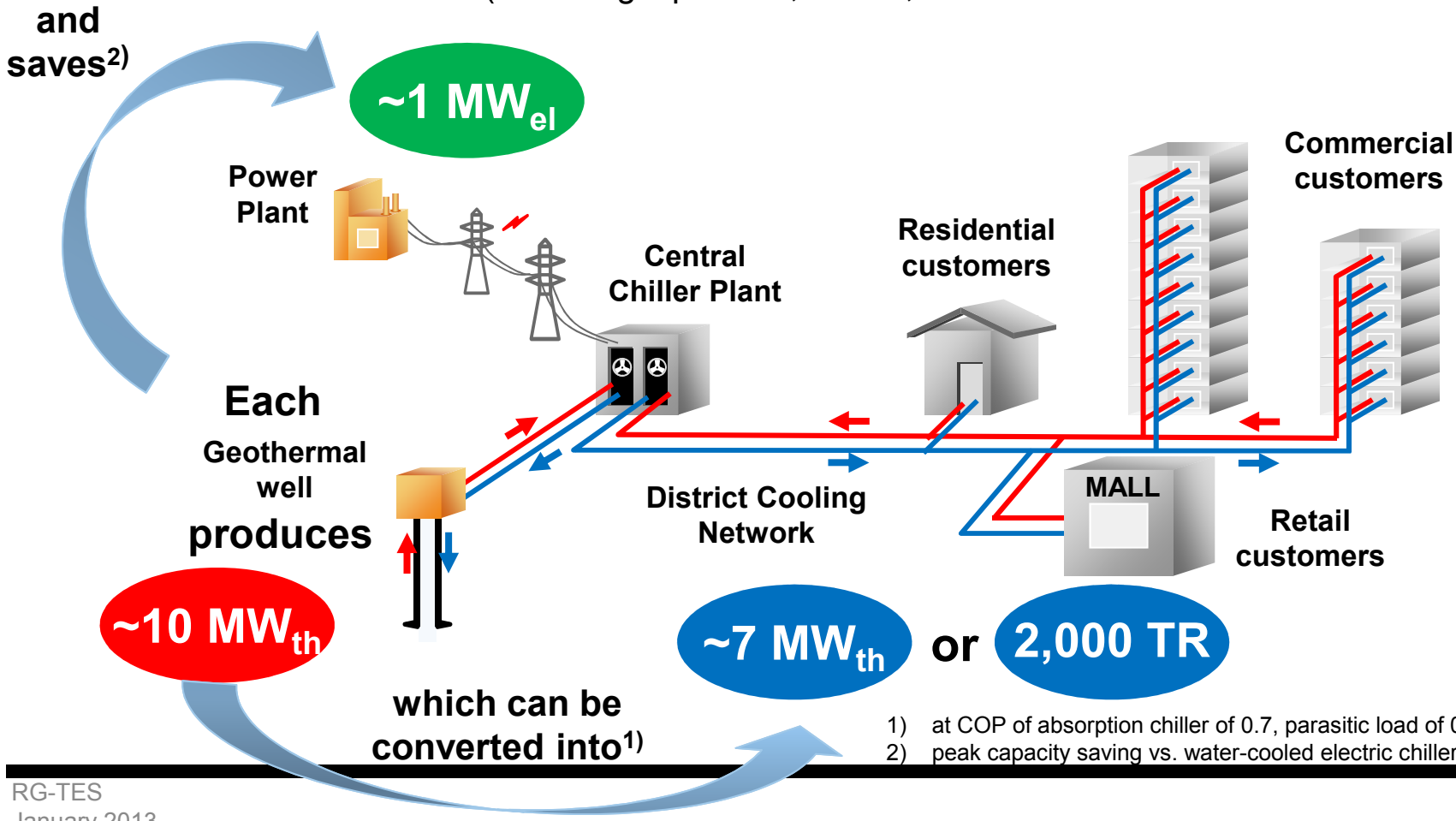


Source: DC PRO, Thermax, RG analysis Note: Assumes absorption chiller as part of larger DCS

Based on these savings, one geothermal well in a cooling application replaces approx. 1 MW of power plant capacity

Potential Electric System Capacity Savings of Geothermal Cooling

Baseline scenario (at 100 kg/s per well, 100°C, ΔT of 30°C vs. conventional district cooling)



1) at COP of absorption chiller of 0.7, parasitic load of 0.5 kWh / TR
2) peak capacity saving vs. water-cooled electric chiller at 1.0 kWh / TR

Another example of low-enthalpy geothermal use is desalination via Multi-Effect Distillation (MED)

Thermal desalination of seawater requires the use of large amounts of energy

- **Inlet temperature range:** 100-70°C
- **Process temperature range:** 50-70°C
- **Energy consumption:** 1.5 kWh_{el} /m3 + 60-80 kWh_{th}/m3
- **Capacities:** Individual units range between 600 m3/day to 68,190 m3/day depending on use and manufacturer

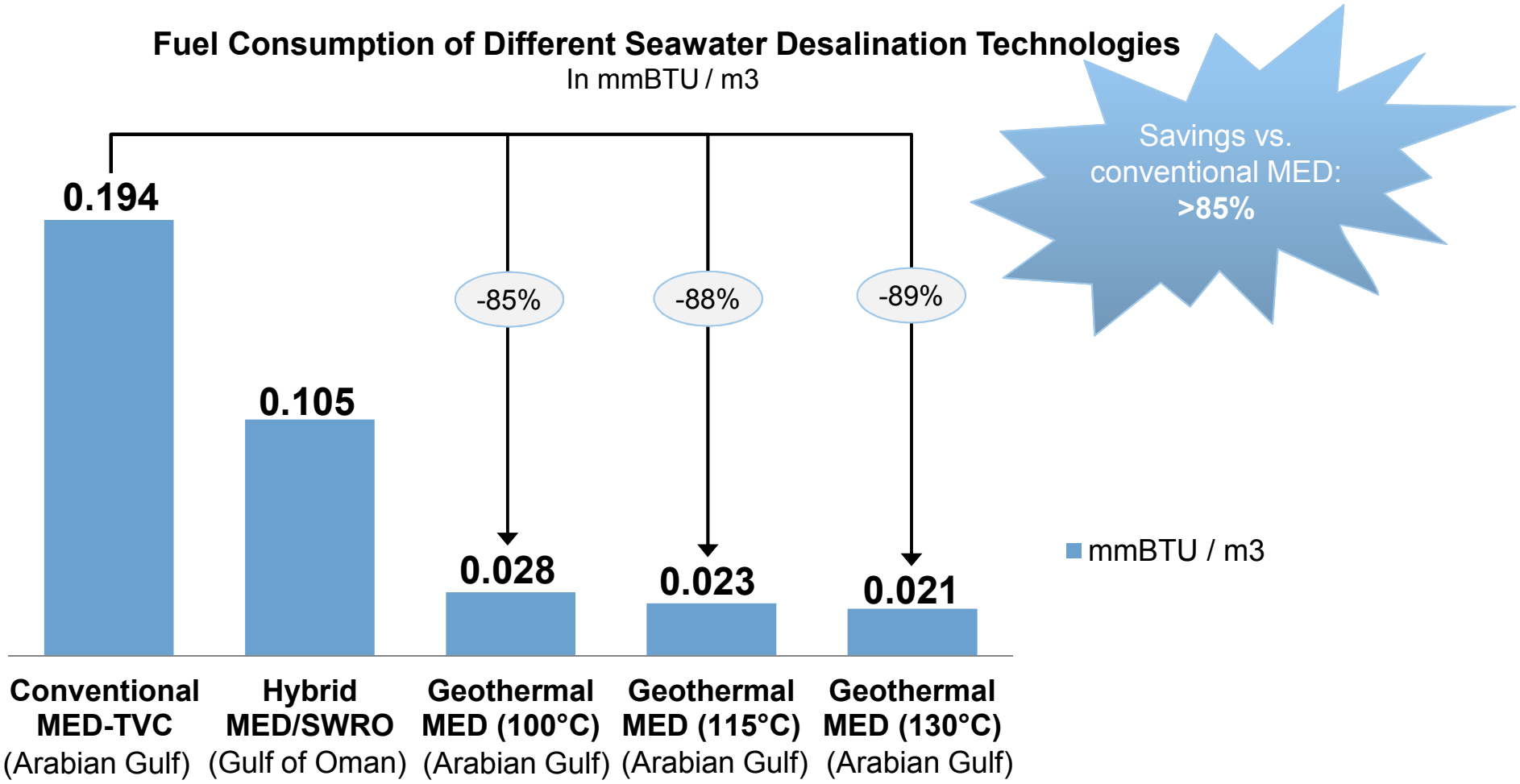
Perfect for low-temperature geothermal

Fujairah II plant, UAE **Picture: Sidem(Veolia)**

Geothermal desalination combines two proven technologies: Geothermal heat and MED.

Source: SAAD, Mohammad Amin (2012), International Conference on Desalination and sustainability Morocco 2012 & Ambata calculations

The fuel savings of using geothermal desalination are massive



Consequently other countries have started to develop geothermal desalination, for example in Greece

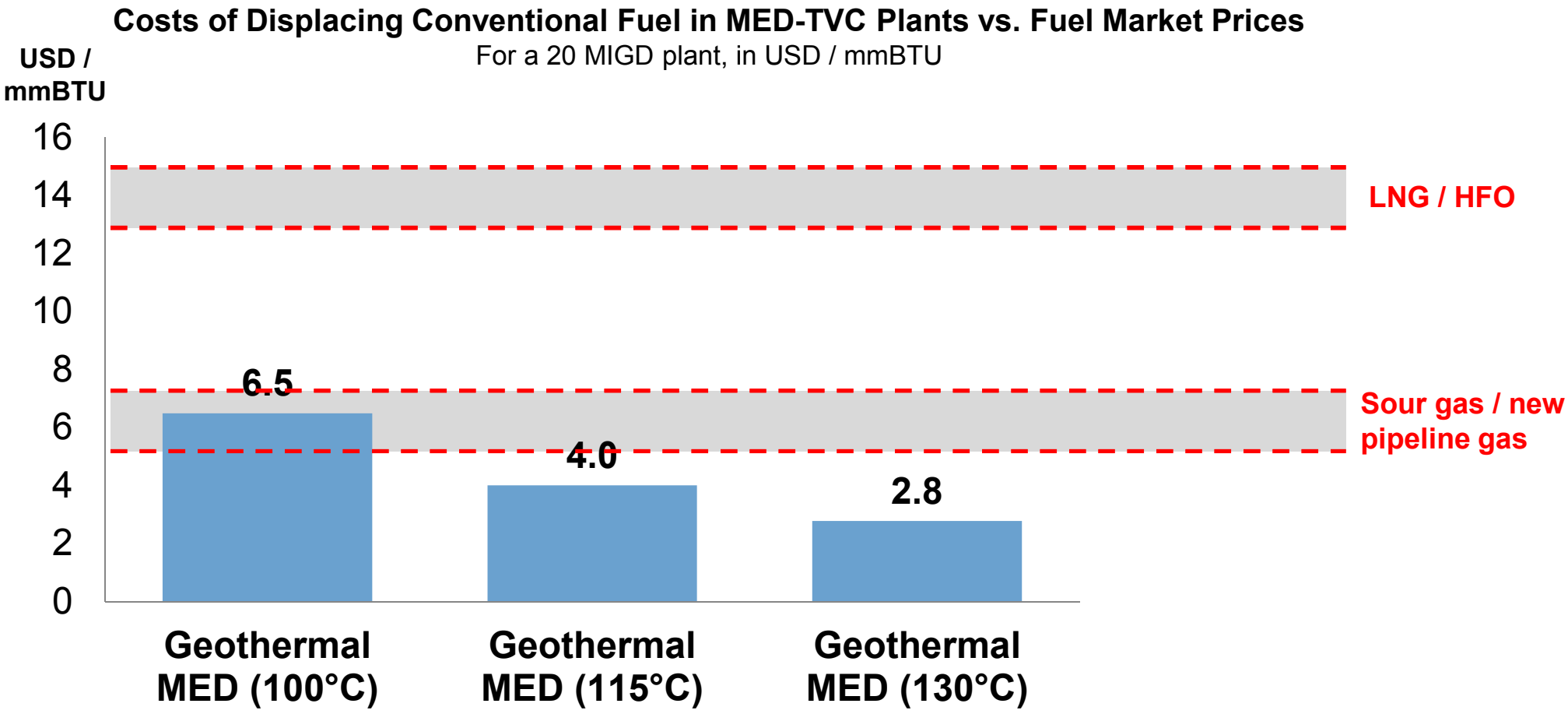
Geothermal Desalination Case Study: Milos Island, Greece

- The first of it's kind pilot plant, located in Vounalia, on the Greek island of Milos
- Production wells drilled in 2004
- Plant due to generate 2,000 m^3/day of drinking water & a name-plate power capacity of 500 kW_e.
- Estimated water production costs at \$1.95 / m^3
- Water provided by a MED-TVC unit, electricity generation is with an Organic Rankine Cycle (ORC).

Milos Power & Desalination Plant Picture: Eco-Logica Agina

Proves the geothermal-desalination concept

We believe the cost of displacing conventional energy in MED desalination to be commercially competitive today



1) Calculated by comparing the fuel consumption of power plants with similar outputs with & without associated water production. Source: Fisia Italimpianti, RG analysis

Conclusions

- The low-enthalpy geothermal resources in the Middle East are much greater than most people think
- Low-enthalpy geothermal energy shows a good match with several regional applications responsible for a large share of overall energy demand
  - **Desalination:** The geothermal resources in the region (tens of GW) could power a substantial share of the thermal desalination in the region
  - **District cooling:** Regional matching required but potential is still significant
  - **Low pressure steam generation :** Pre-heating with low-enthalpy geothermal heat could reduce energy requirements.
- The economics of low-enthalpy geothermal are attractive
- The primary challenge for the development of low-enthalpy geothermal in the region is awareness, not technology or economics

Low-enthalpy geothermal – other uses around the world

Flower Growing, Kenya

District heating, Iceland

Drying of Tomatoes, Greece

Aquaculture, California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