EUROPEAN CENTER FOR SCIENCE ARTS AND CULTURE (ECSAC) OF LOŠINJ

WORKSHOP ON STATUS AND FUTURE OF GEOTHERMAL ENERGY IN THE PERI-ADRIATIC AREA

VELI LOŠINJ CROATIA
25-27 AUGUST 2014

RECENT ACHIEVEMENTS IN GEOTHERMAL TECHNOLOGY

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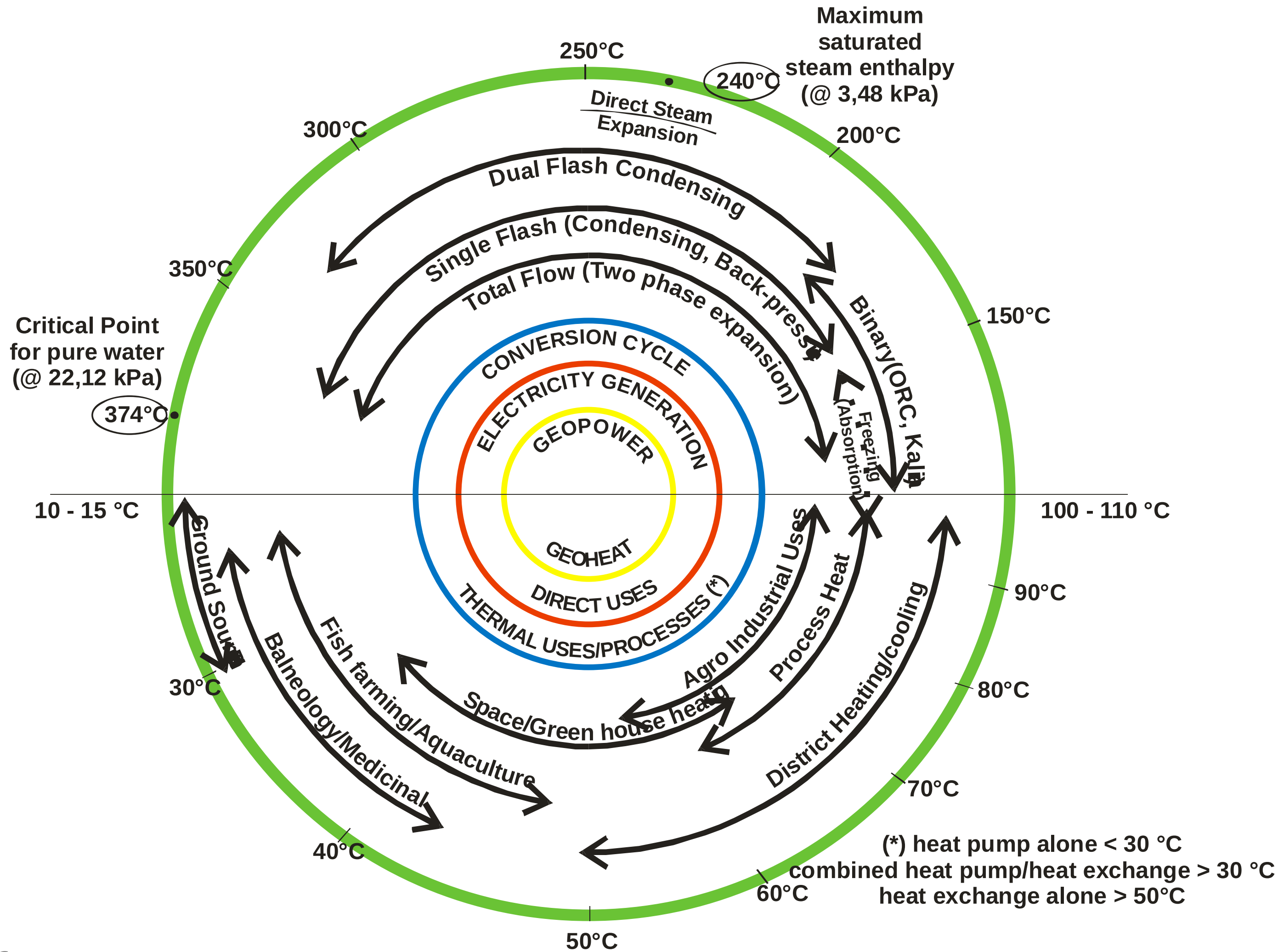
OUTLINE

- OUTLOOK
- KEY ISSUES
- RESERVOIR ASSESSMENT
- WELL TARGETING
- WELL ARCHITECTURE
- SOLUTION GASES
- INJECTIVITY
- THERMOCHEMISTRY
- HIGH TEMPERATURE EQUIPMENT
- SUSTAINABILITY

OUTLOOK

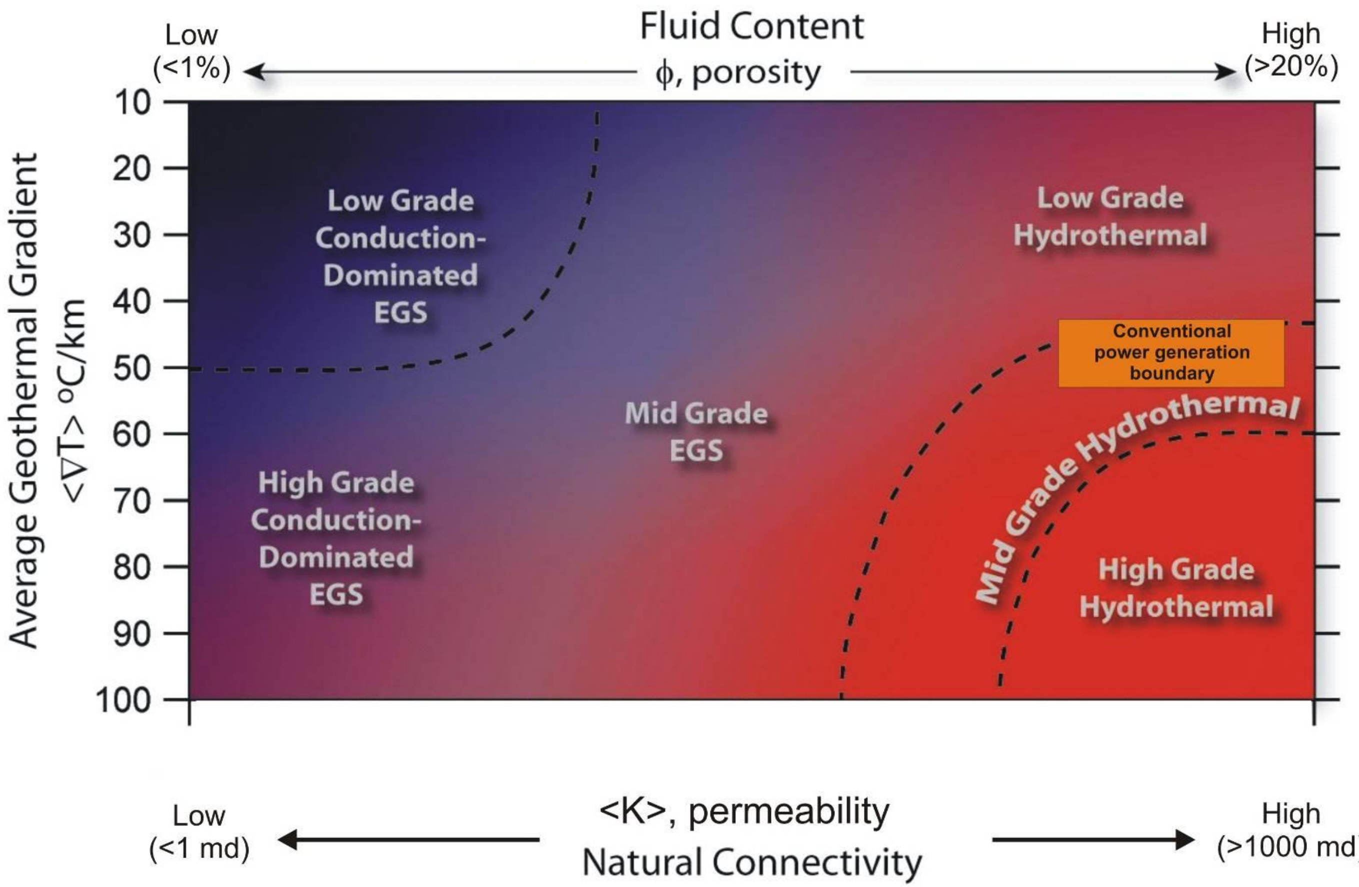
RESOURCE CLASSIFICATION

SIMPLIFIED GEOTHERMAL UTILISATION DIAGRAM



OUTLOOK

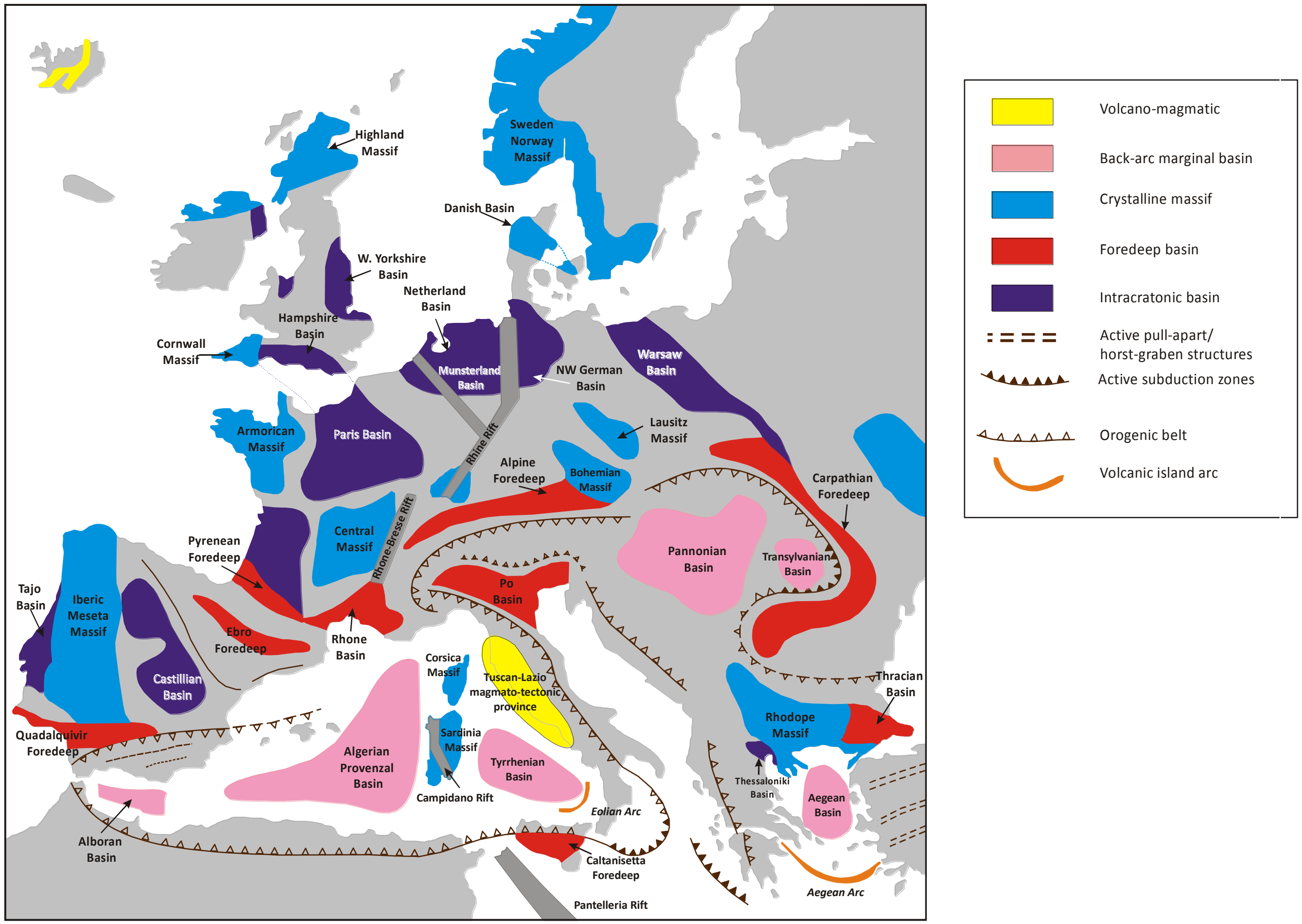
GEOTHERMAL CONTINUUM



(Adapted from J. Tester)

OUTLOOK

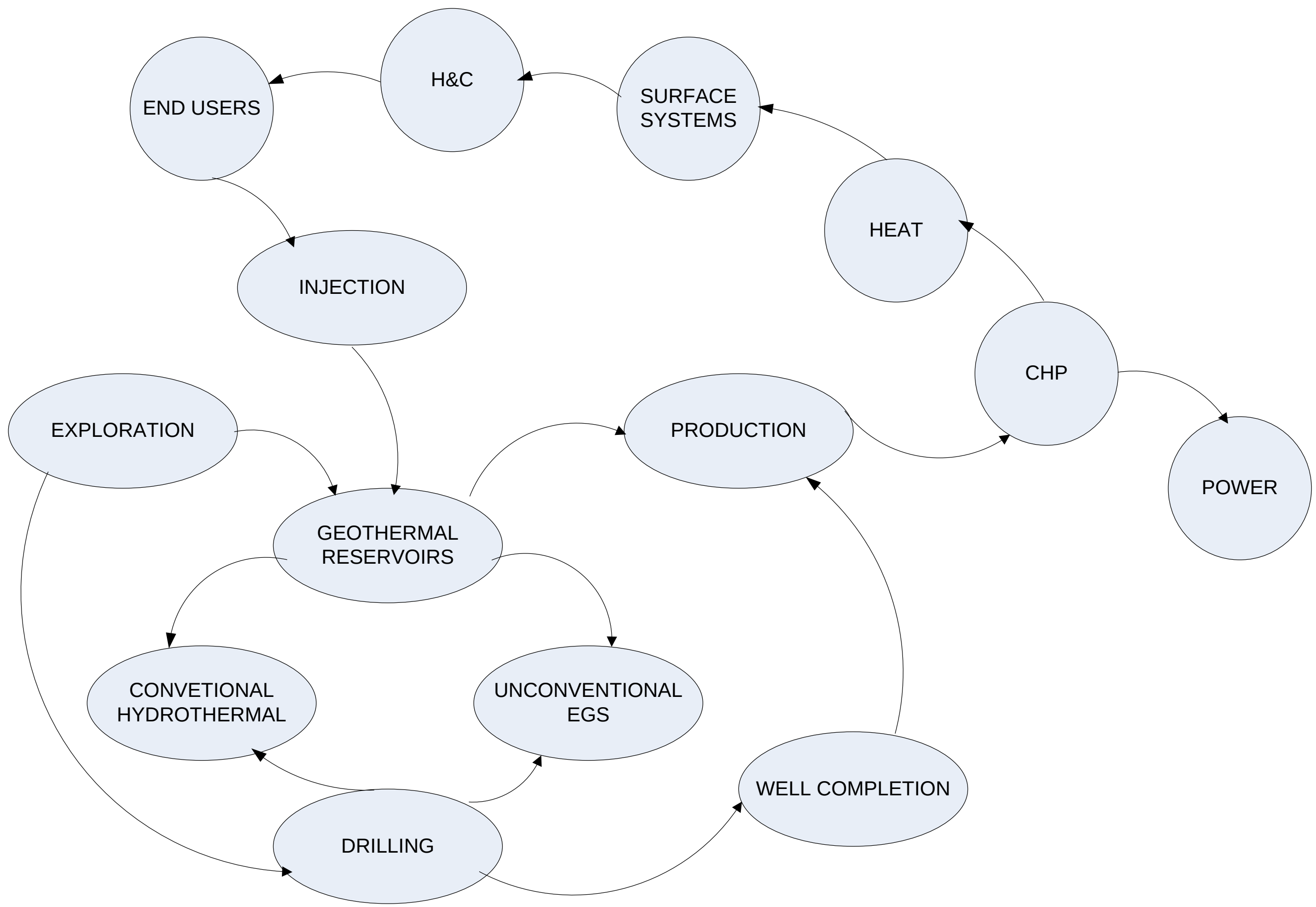
EUROPEAN GEODYNAMIC ENVIRONMENTS



EUROPEAN GEODYNAMIC SETTINGS
(after C. Sommaruga)

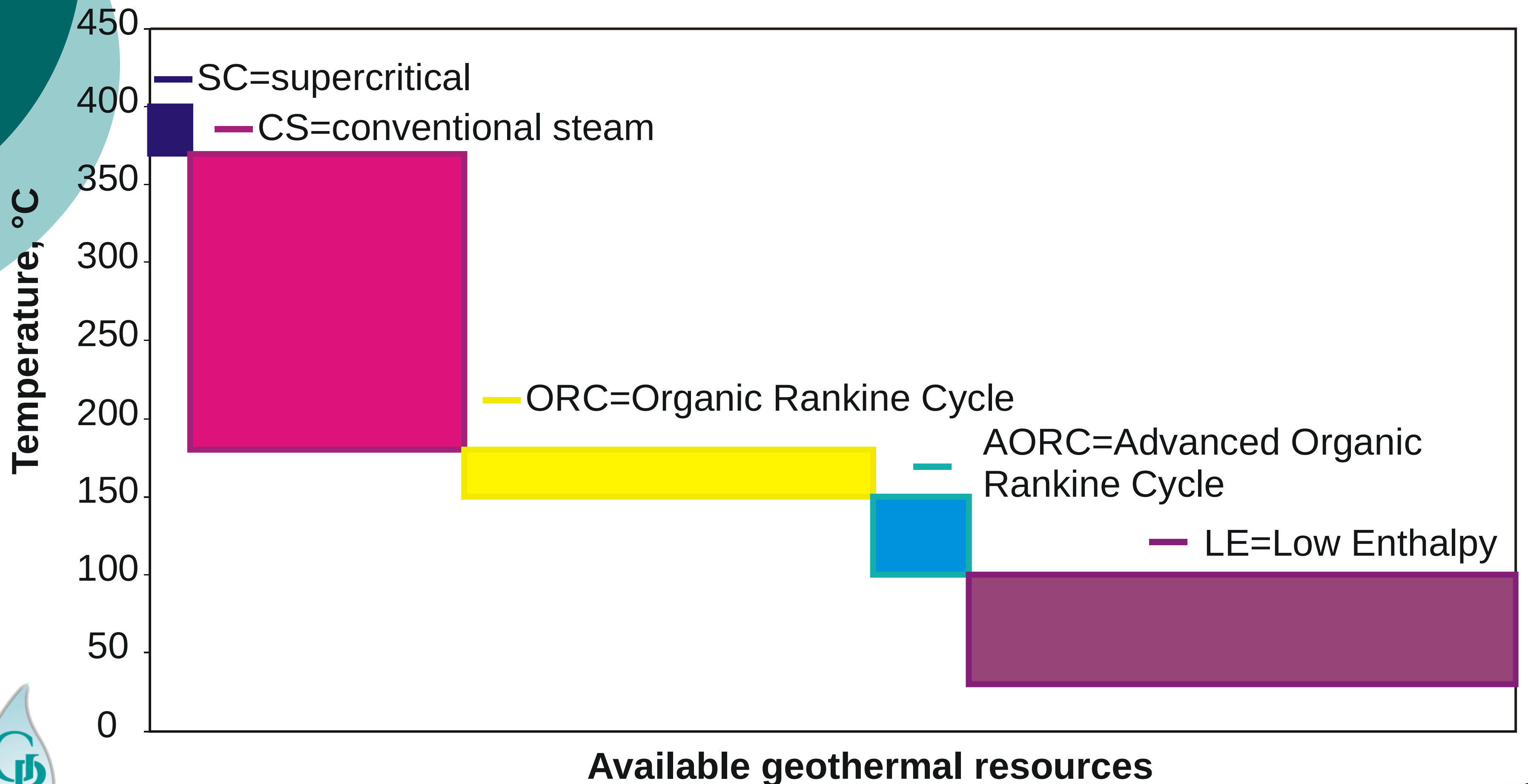
OUTLOOK

GEOTHERMAL H&C AND POWER PRODUCTION
A SYSTEM OVERVIEW



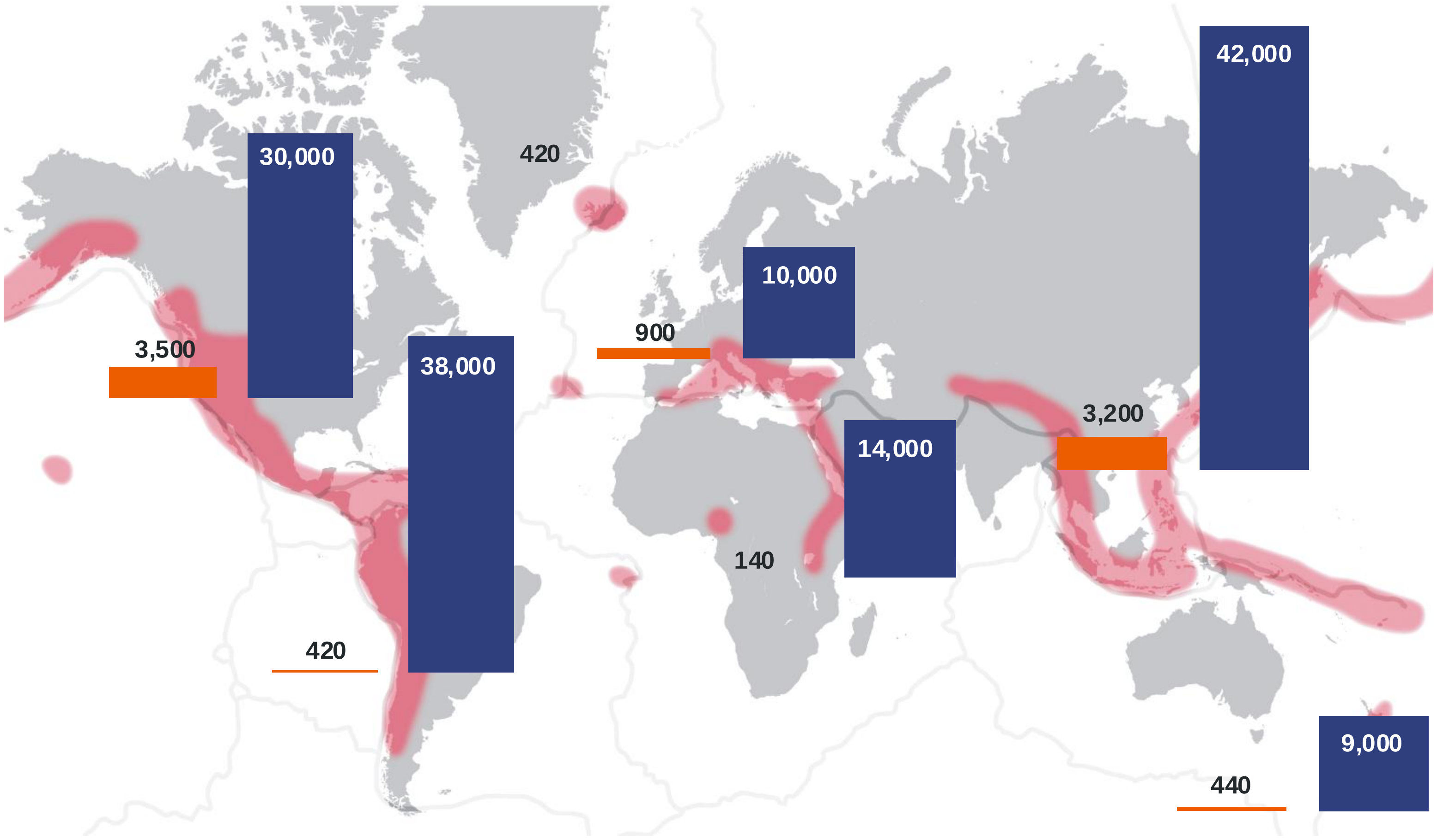
OUTLOOK

GEOTHERMAL RESOURCE UTILISATION POTENTIAL
A TENTATIVE ASSESSMENT



KEY ISSUES

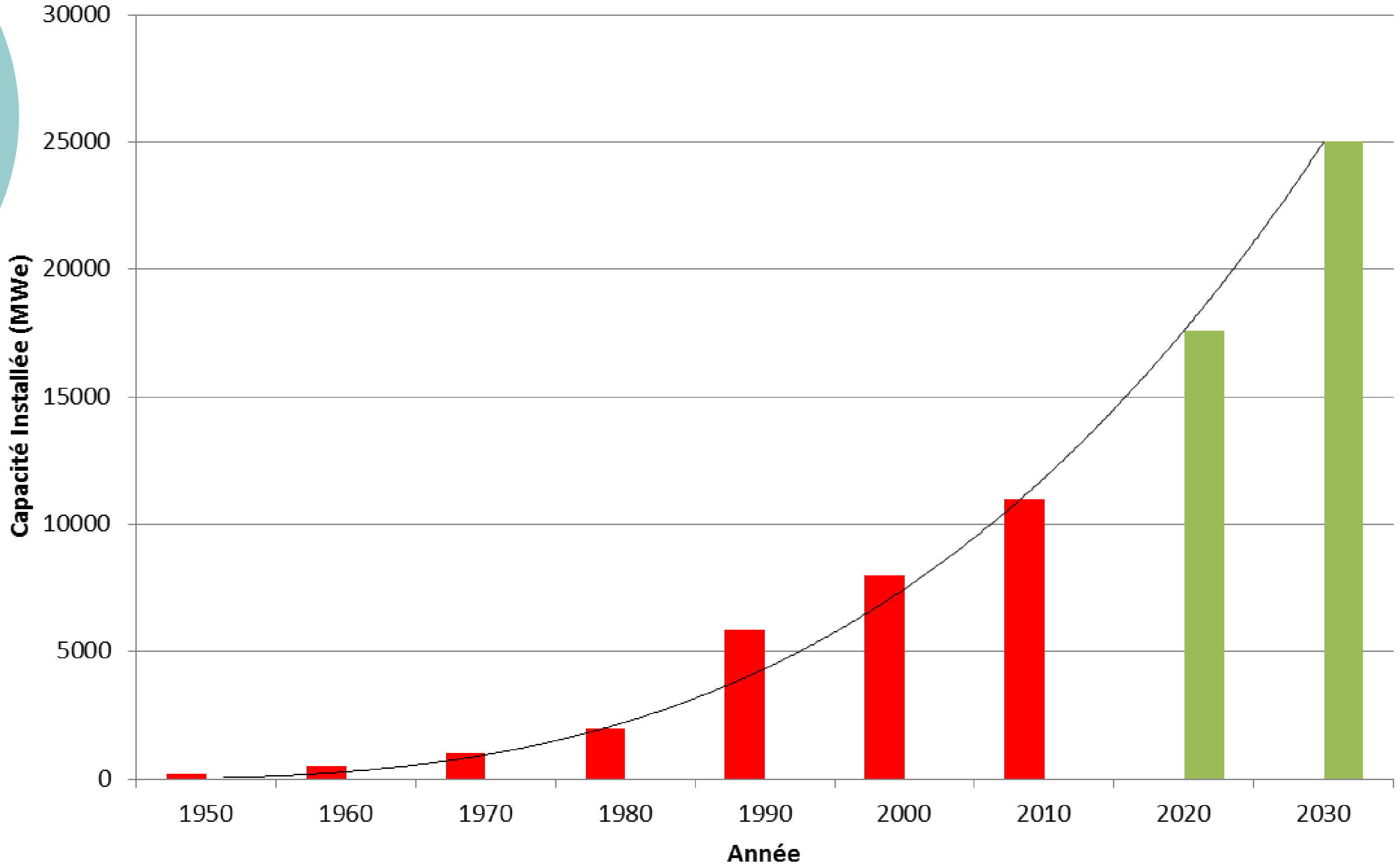
KEY ISSUES
WORLDWIDE GEOPOWER HYDROTHERMAL POTENTIAL



SOURCE: GLITNIR

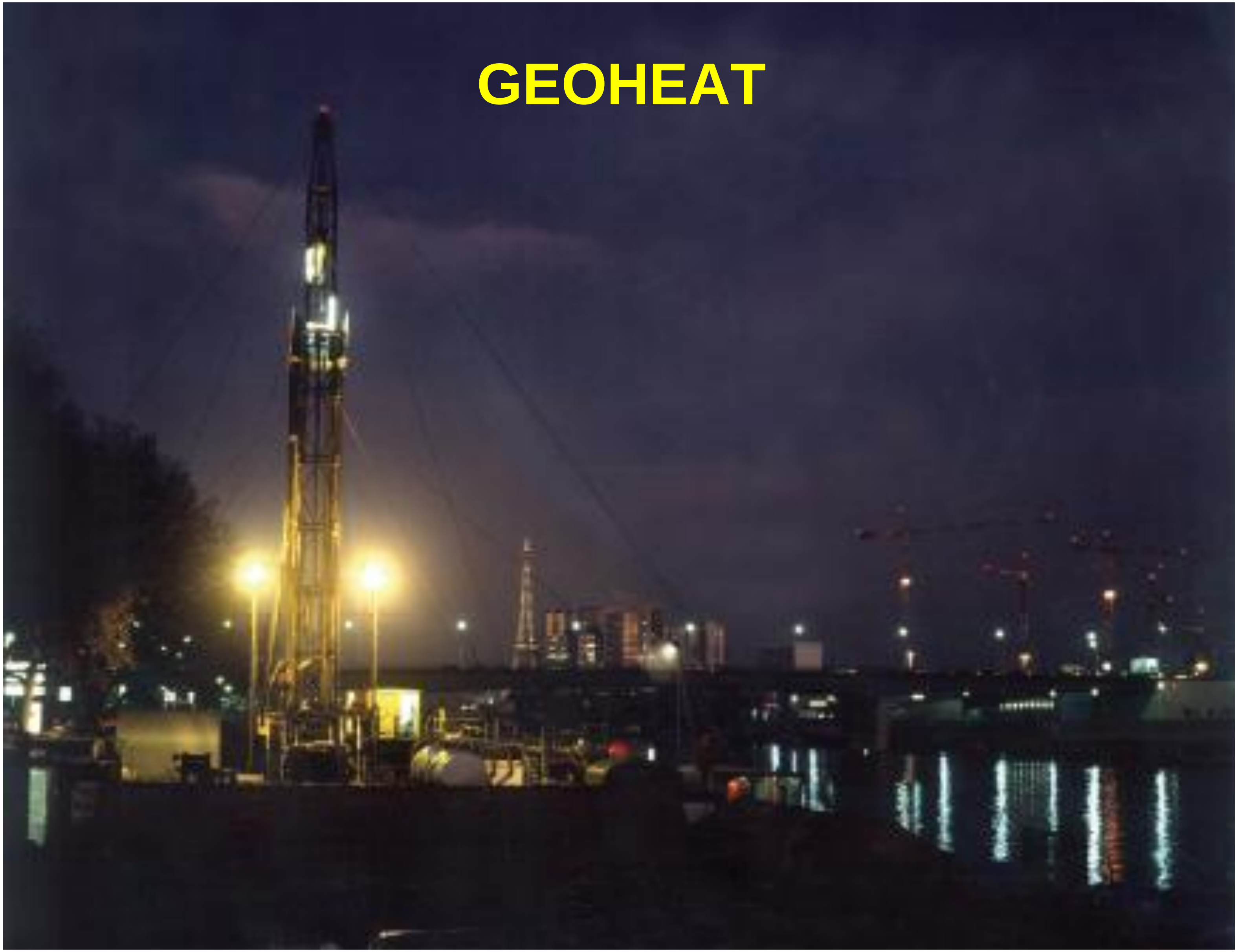
KEY ISSUES

DEVELOPMENT OF GEOPOWER SOURCES PRESENT (2012) AND PROJECTED (2030) STATUS



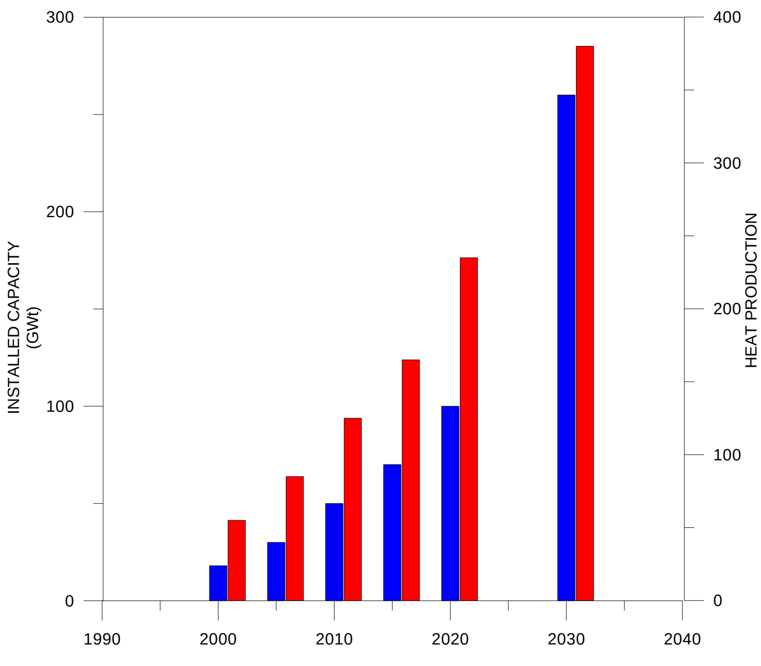
Source: EGEC (Bertani), WORLD BANK

KEY ISSUES

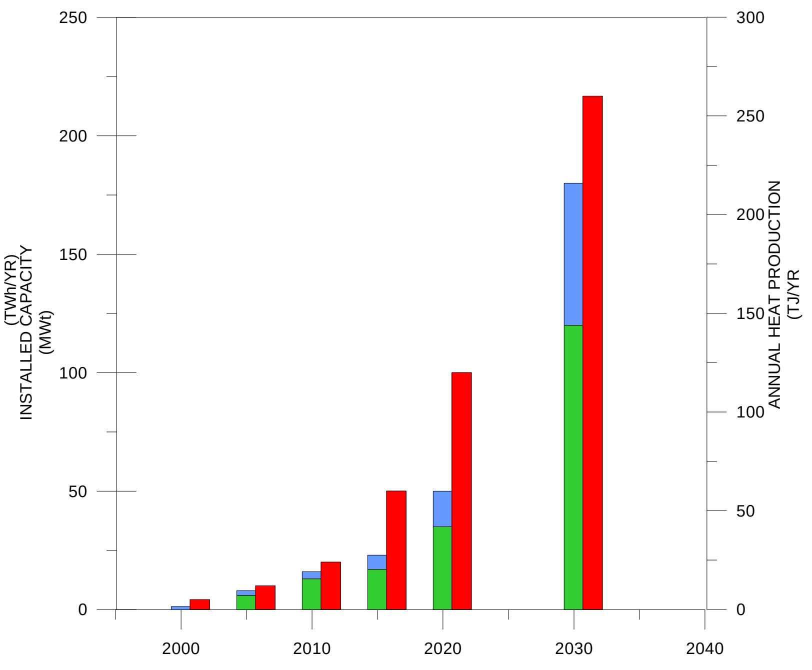


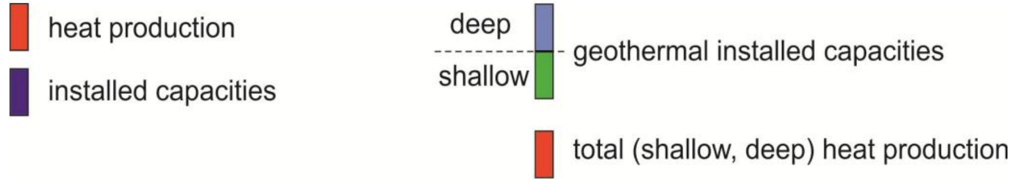
KEY ISSUES
GEOHEAT
PAST, PRESENT AND PROJECTED STATUS

A. WORLDWIDE



B. EU 27





Source: EGEC, IGA

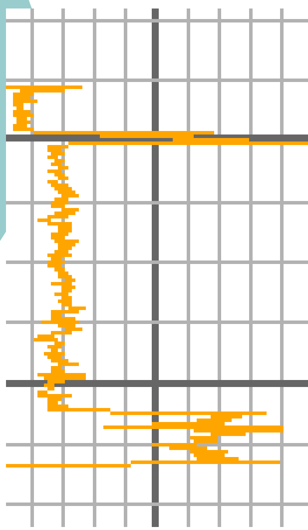
KEY ISSUES

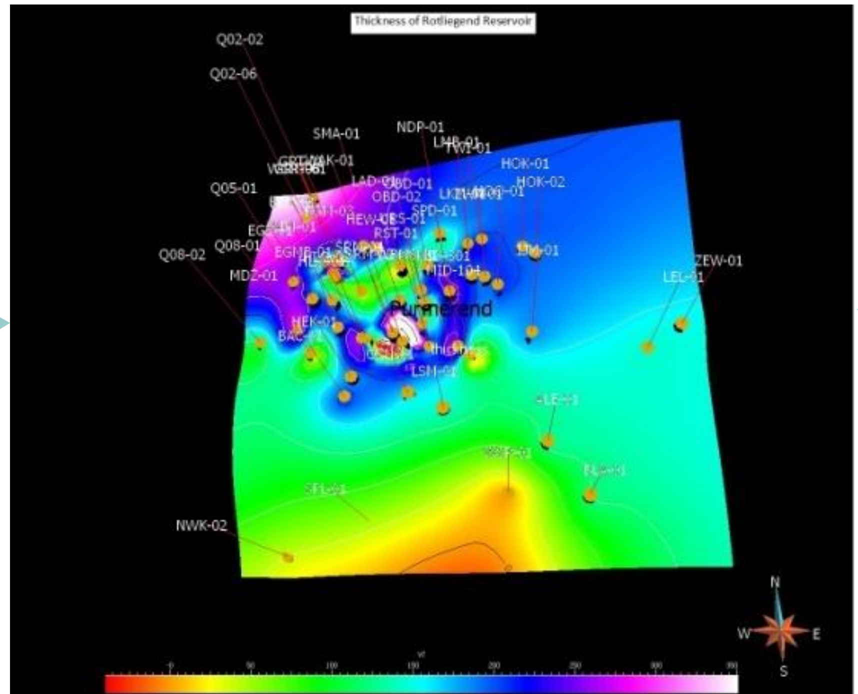
R&D TARGETS
INCREASE GEOTHERMAL SHARE BY

- MAXIMISING THE RESOURCE
- MINIMISING THE RISKS
- OPTIMISING HEAT EXTRACTION
- REDUCING COSTS
- MATCHING H&C DEMAND
- LAST BUT NOT LEAST ACHIEVING SUSTAINABLE MANAGEMENT

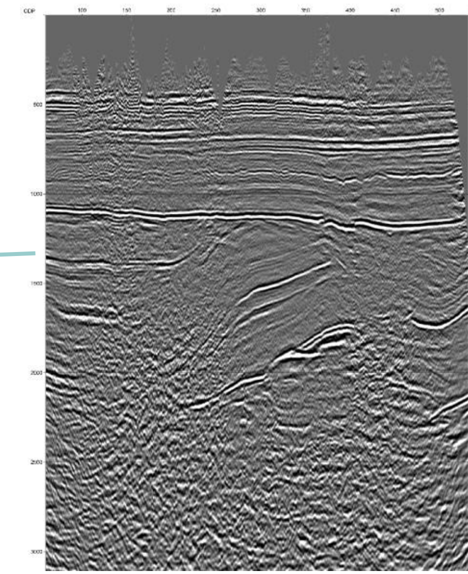
3D REGIONAL GEOLOGICAL MODEL

Borehole data:
logs and lithostratigraphic columns





Seismic data

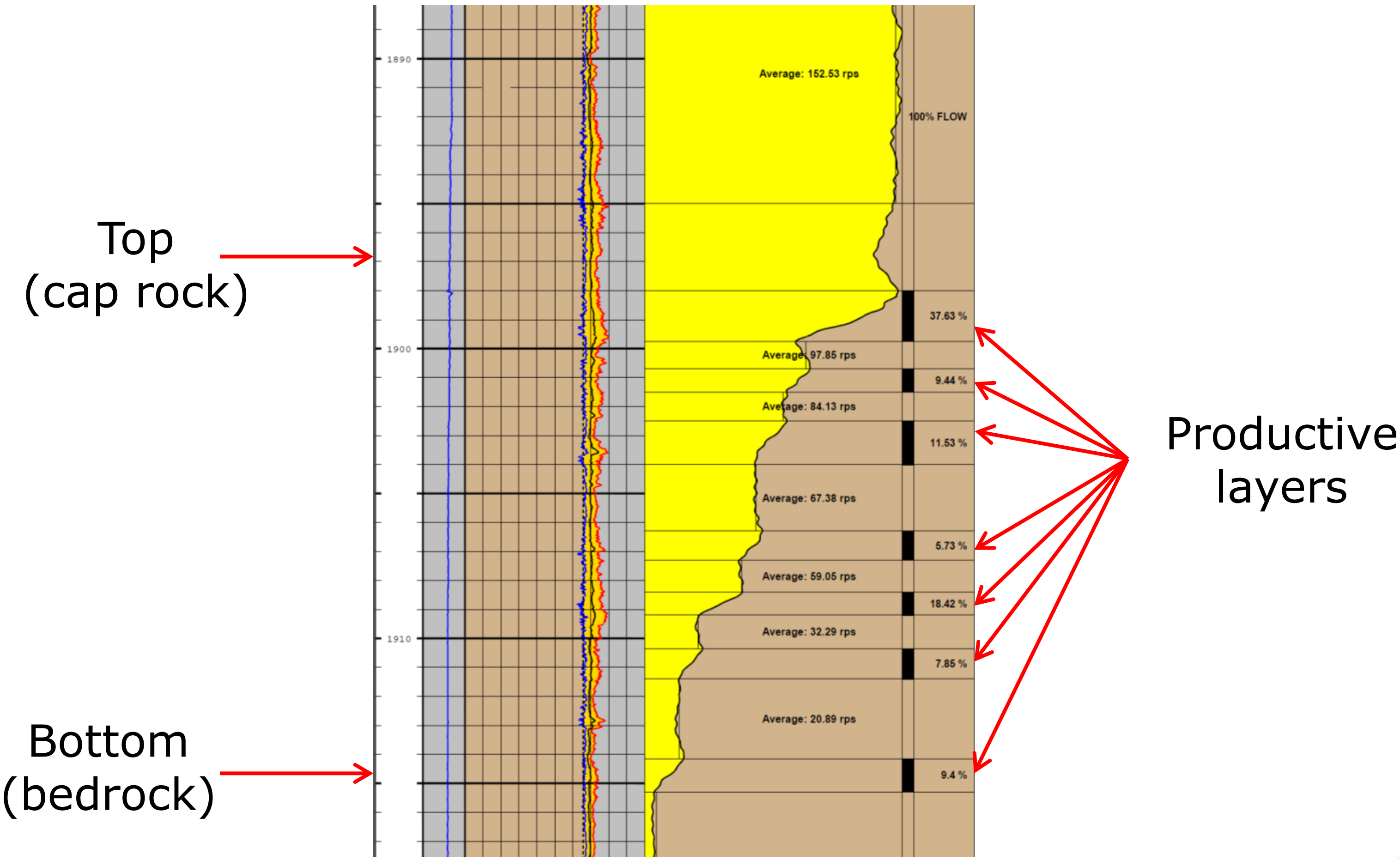


	2364	2387	Z1 Upper Anhydrite Member
	2387	2622	Z1 Salt Member
	2622	2661	Z1 Lower Anhydrite Member
	2661	2678	Z1 Lower Claystone Member
	2678	2679	Coppershale Member
	2679	2888	Slochteren Formation
	2888	2913	Caumer Subgroup

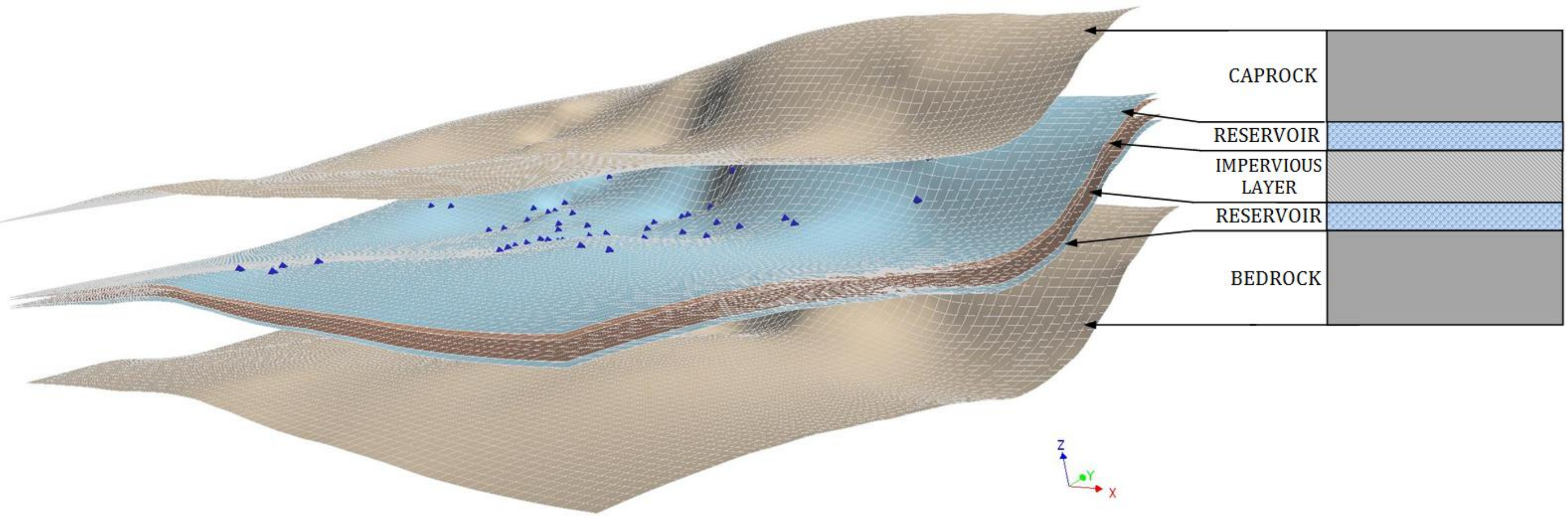
Interpolated data extracted from existing databases and geological atlases

RESERVOIR ASSESSMENT
EFFECTIVE THICKNESS (NET PAY)

FLOWMETER LOG OF RESERVOIR SECTION



RESERVOIR ASSESSMENT
GOCAD 3D VIEW OF THE SANDWICH MULTILAYERED RESERVOIR STRUCTURE

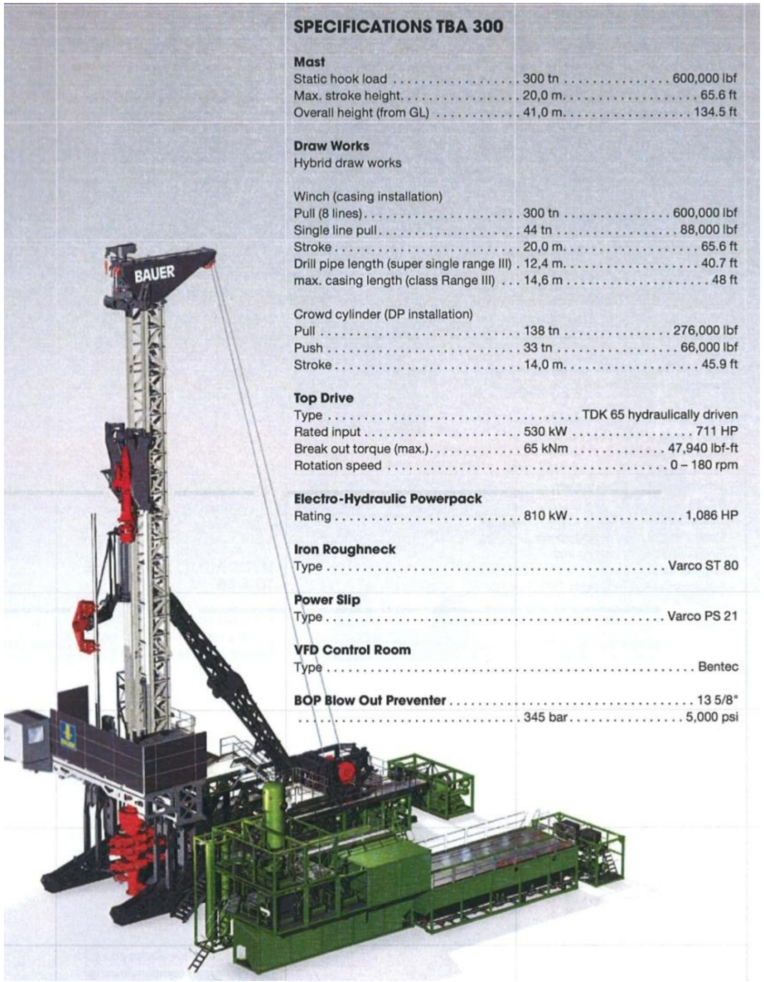


WELL TARGETING

NEW GENERATION OF HYDRAULIC HEAVY DUTY RIG

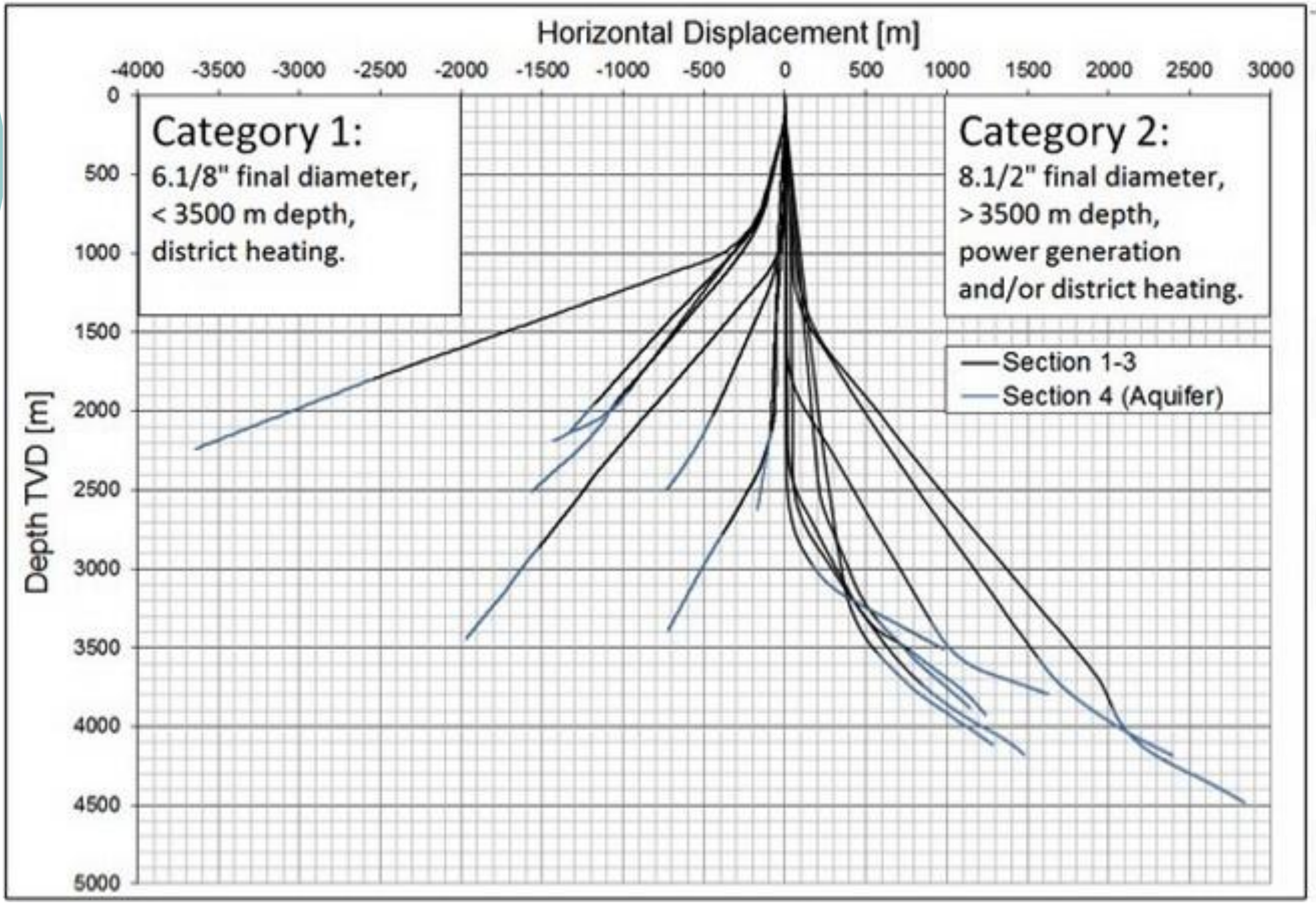
Source: HERRENKNECHT

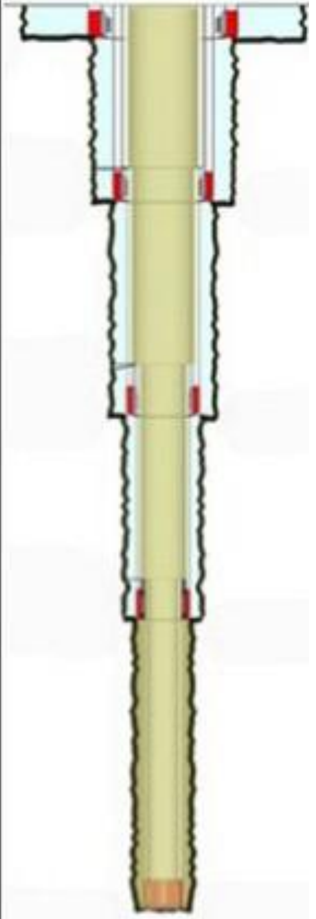
NOVEL COMPACT HYDRAULIC RIG DESIGN



Source : BAUER

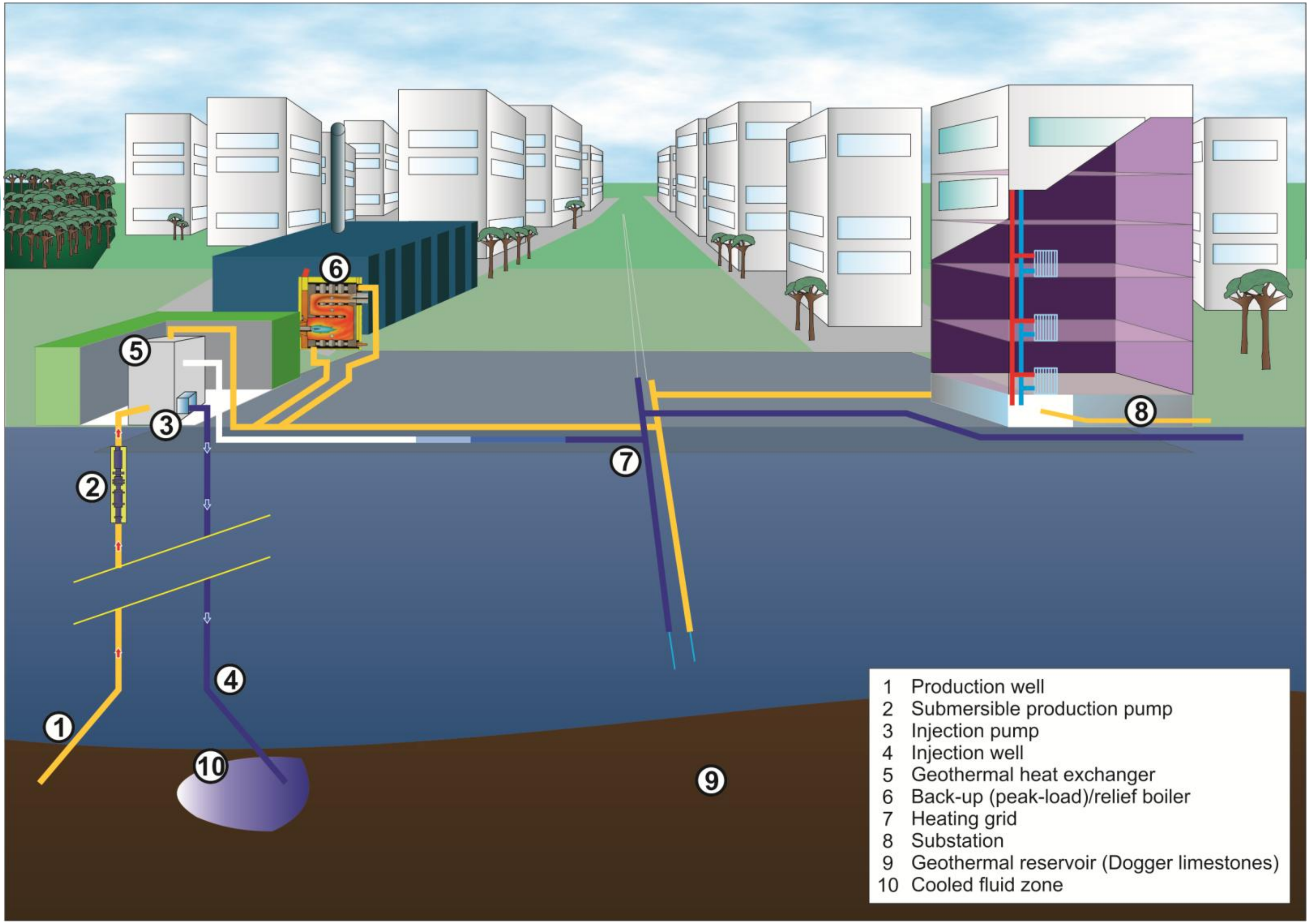
MOLASSE BASIN, MALM RESERVOIR TYPICAL WELL TRAJECTORIES



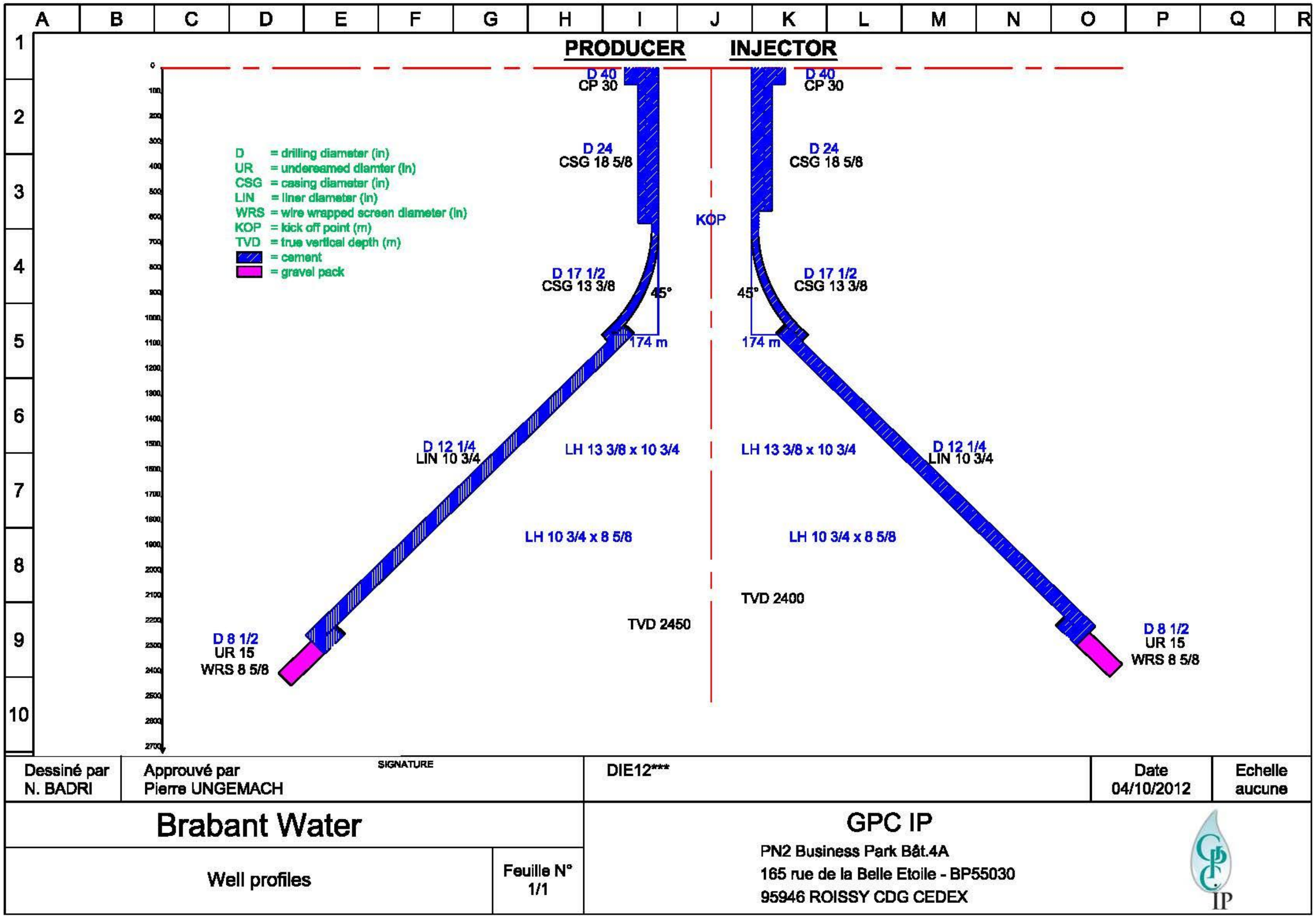


Source: Erdwerk 2014 D-GEO-DAYS PARIS

TYPICAL GDH SCHEME

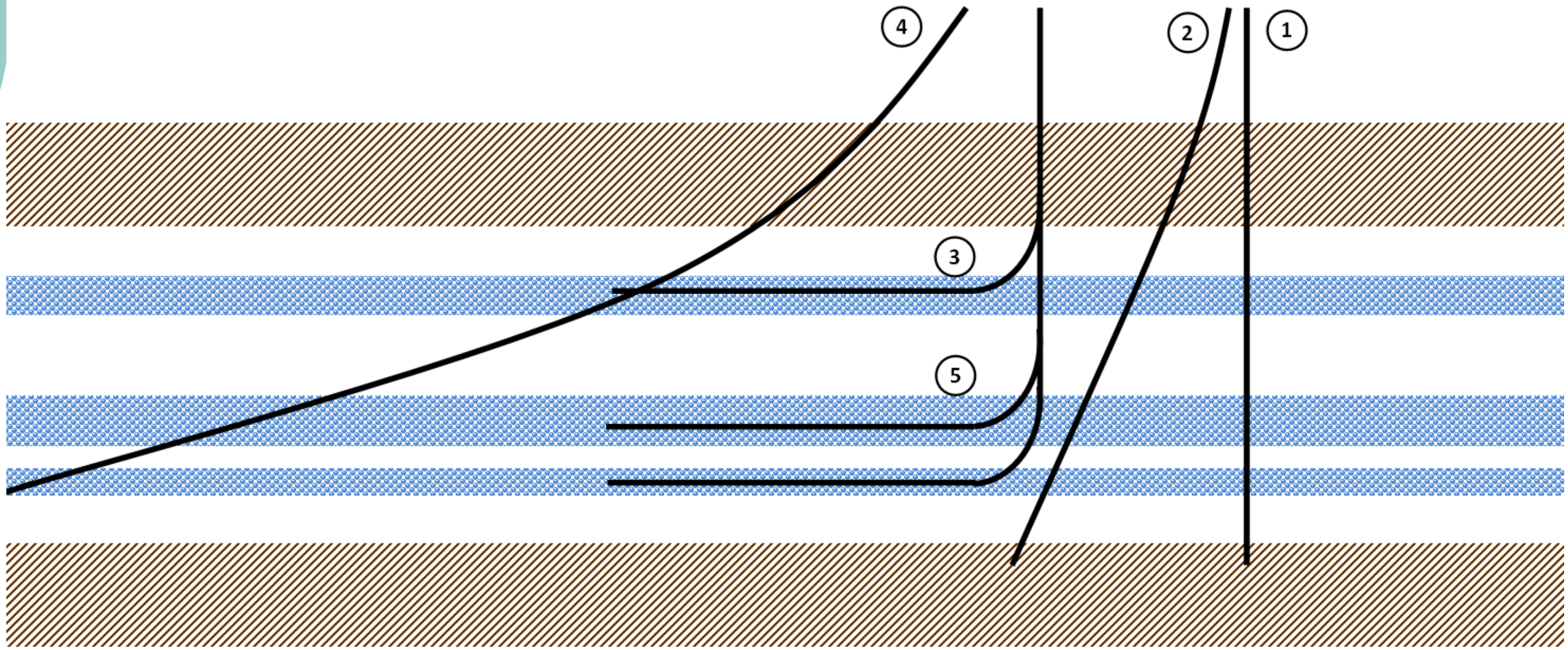


WELL ARCHITECTURE
CLASTIC RESERVOIR



(SUB)HORIZONTAL WELL DESIGNS

CANDIDATE WELL TRAJECTORIES
MULTILAYERED RESERVOIR
CONVENTIONAL (VERTICAL, DEVIATED)
AND SUGGESTED [(SUB)HORIZONTAL] WELL TRAJECTORIES

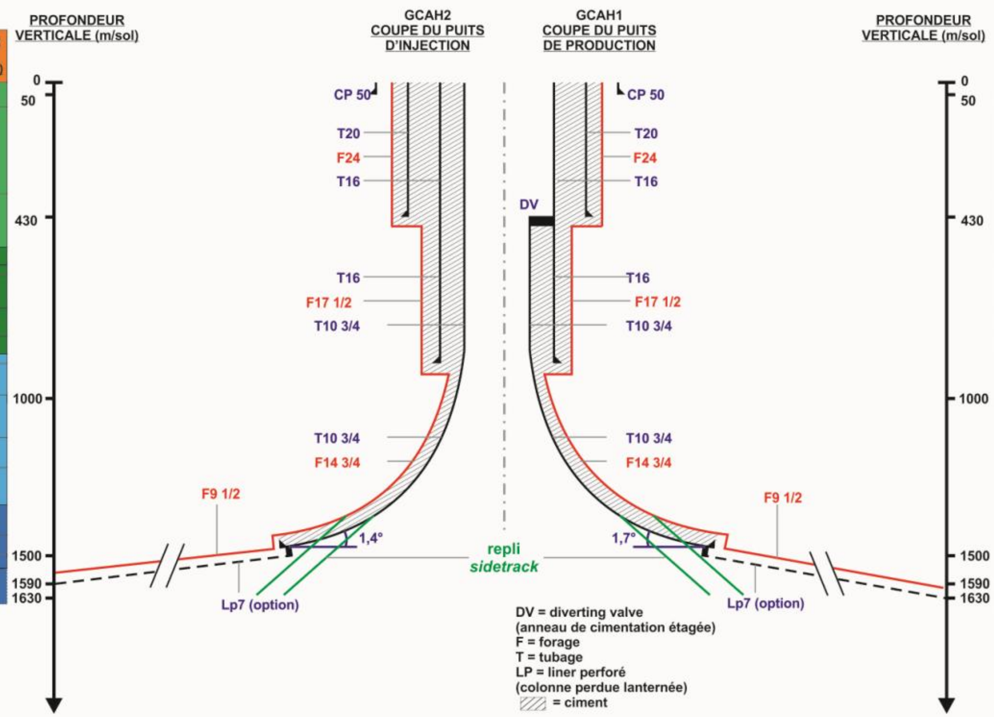


1 Vertical well
2 Deviated well (≠ 30-35°)
3 Horizontal drain intersecting one layer
4 Subhorizontal well (≠80-85°) intersecting all the producing layers
5 Multilateral well, horizontal drains intersecting all the producing layers

SUBHORIZONTAL WELL TRAJECTORIES AND CONVENTIONAL FALL BACK OPTION

GCAH2 INJECTEUR

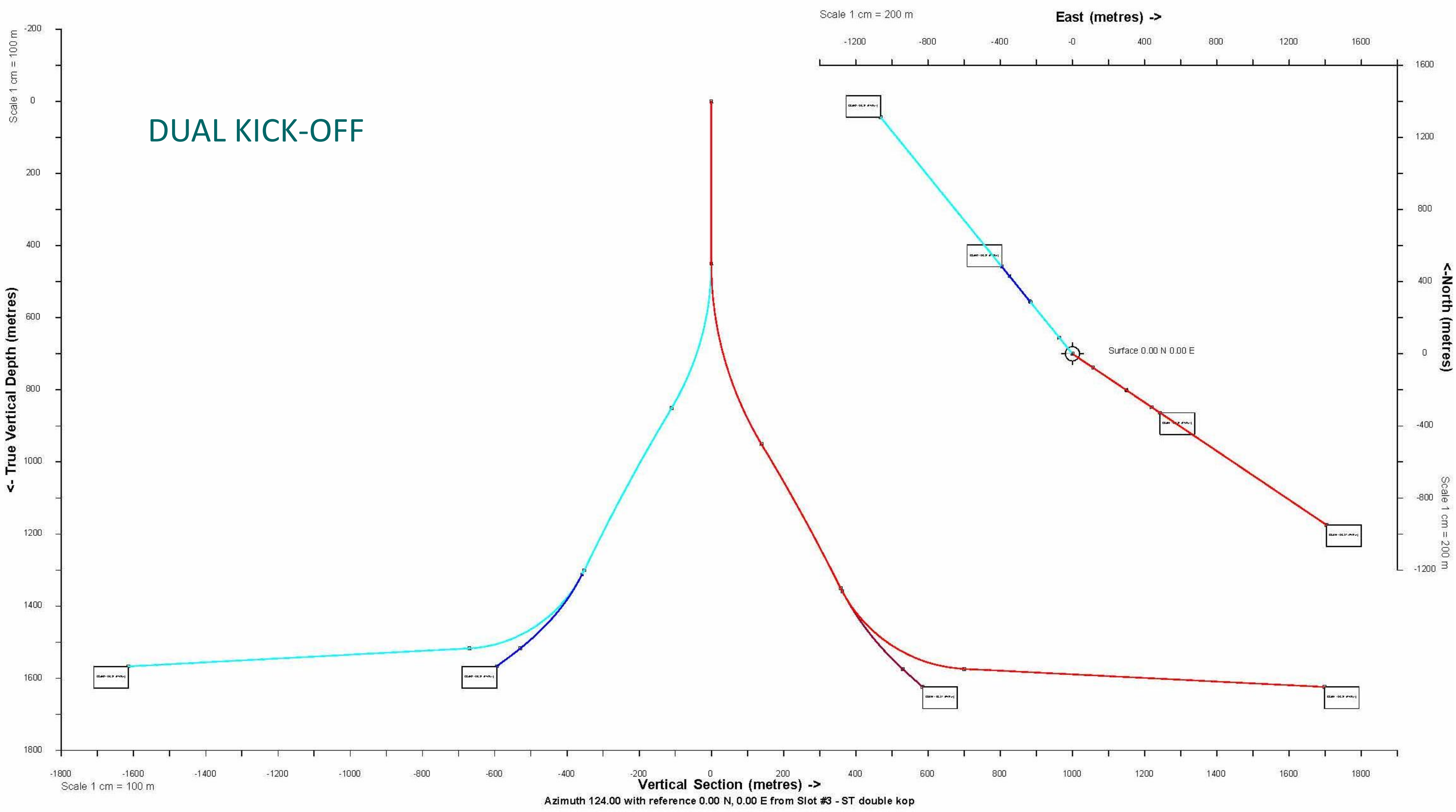
STRATIGRAPHIE	LITHOLOGIE	EPAISSEUR (m)	PROFONDEUR VERTICALE DU TOIT (m/sol)
Eocène	Calcaires, sables, argiles	74	0
Sénonien	Craie blanche à silex.	281	74
Turonien	Craie grise à silex.	165	355
Cénomanien	Calcaire silto-sableux,argileux.	56	519
Gault	Argiles gris-sombre.	27	575
Albo-Aptien	Sable glauconieux (et argiles).	99	602
Barrémien	Argile à intercalation de sable (et lignite).	82	701
Néocomien	Sables et argiles.	70	783
Purbeckien	Marnes et dolomies.	22	853
Portlandien	Calcaires et marnes.	116	875
Kimméridgien	Marnes et argiles calcaires.	130	991
Séquanien	Calcaire plus ou moins oolithique.	94	1121
Rauracien	Calcaire plus ou moins oolithique.	115	1215
Argovien	Marnes et argiles calcaires.	92	1330
Oxfordien	Calcaire argilo-sableux. Marnes sableuses et grès.	58	1422
Callovien	Argiles et marnes	37	1481
Bathonien	Calcaires micritiques,graveleux et oolithiques.	100	1517



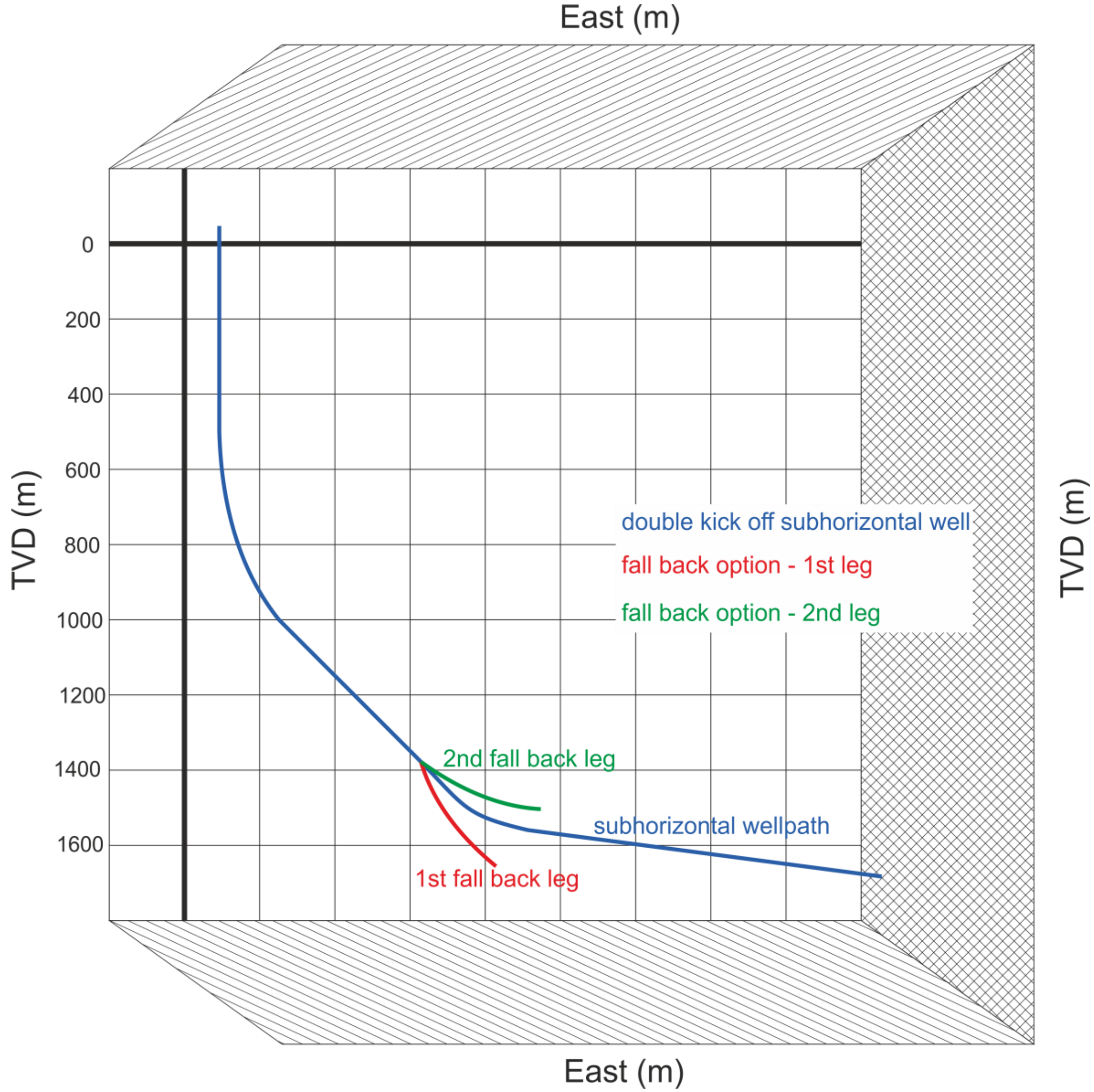
GCAH1 PRODUCTEUR

STRATIGRAPHIE	LITHOLOGIE	EPAISSEUR (m)	PROFONDEUR VERTICALE DU TOIT (m/sol)
Eocène	Calcaires, sables, argiles	77	0
Sénonien	Craie blanche à silex.	275	77
Turonien	Craie grise à silex.	169	352
Cénomanien	Calcaire silto-sableux,argileux.	57	521
Gault	Argiles gris-sombre.	31	577
Albo-Aptien	Sable glauconieux (et argiles).	106	609
Barrémien	Argile à intercalation de sable (et lignite).	85	715
Néocomien	Sables et argiles.	60	800
Purbeckien	Marnes et dolomies.	30	860
Portlandien	Calcaires et marnes.	123	890
Kimméridgien	Marnes et argiles calcaires.	137	1013
Séquanien	Calcaire plus ou moins oolithique.	97	1149
Rauracien	Calcaire plus ou moins oolithique.	117	1246
Argovien	Marnes et argiles calcaires.	95	1363
Oxfordien	Calcaire argilo-sableux. Marnes sableuses et grès.	70	1459
Callovien	Argiles et marnes	46	1528
Bathonien	Calcaires micritiques,graveleux et oolithiques.	100	1574

SUBHORIZONTAL WELL TRAJECTORIES AND CONVENTIONAL FALL BACK OPTION



UPGRADING WELL PERFORMANCE
3D MULTIPLE WELL PATHS

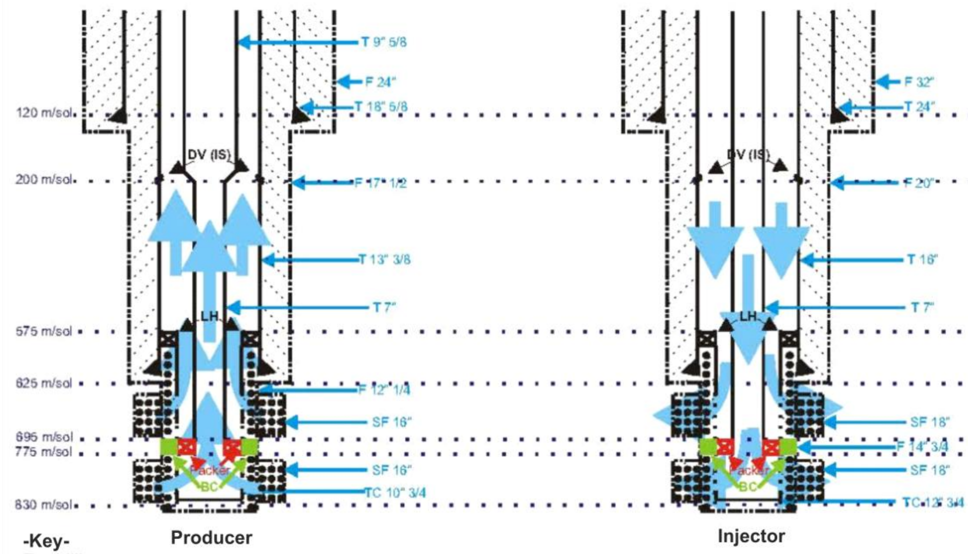


DUAL COMPLETIONS GEOTHERMAL DISTRICT HEATING & COOLING (GDHC)

MEDIUM DEPTH SEATED RESERVOIRS

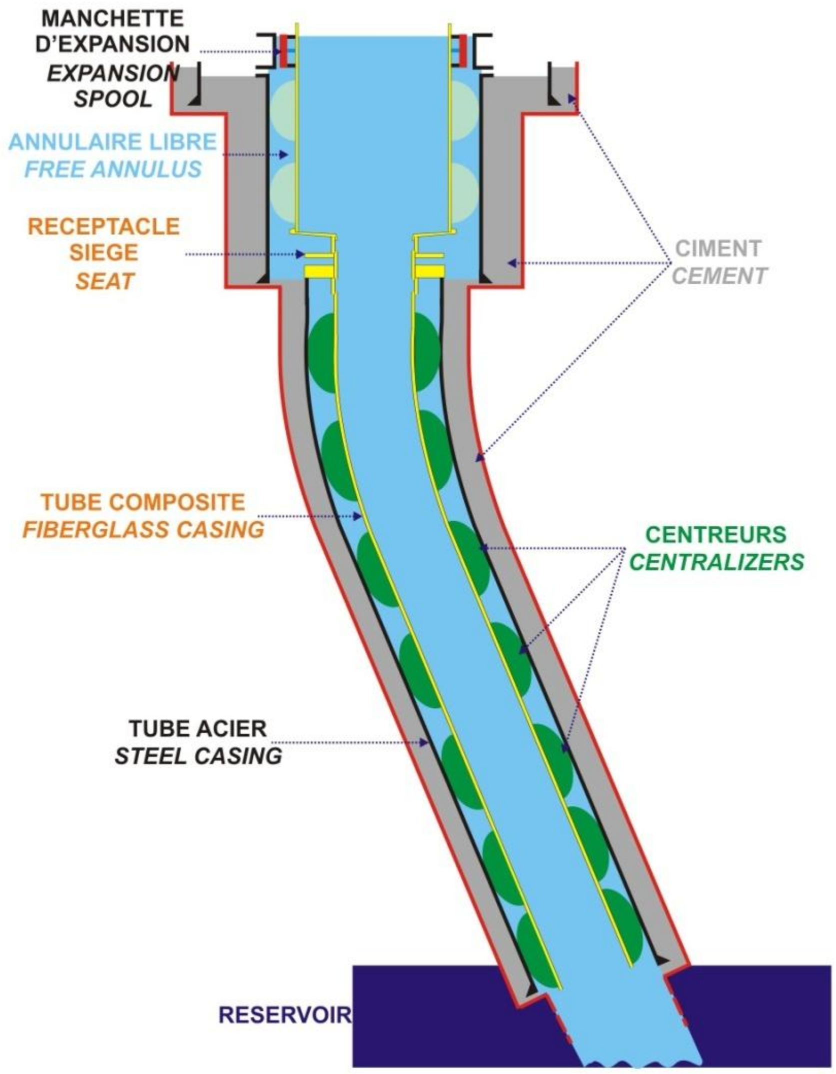
Depth			N°	Thickners (m)	Transmissivity (m²/s)
	0				
625	12,5	Albo-Aptien 1	1	25	$5\ 10^{-3}$
	35	Aquitard	2	20	k_v = 15 mD
695	57,5	Albo-Aptien 2	1	25	$5\ 10^{-3}$
	110	Aquitard (Barremien)	3	80	k_v = 0.1 mD
	157,5	Néocomien 1	4	15	$3,5\ 10^{-3}$
775	175	Aquitard	5	20	k_v = 5 mD
825	192,5	Néocomien 2	4	15	$3,5\ 10^{-3}$
	200				

AQUIFER SYSTEM



GDHC DOUBLET COMPLETION

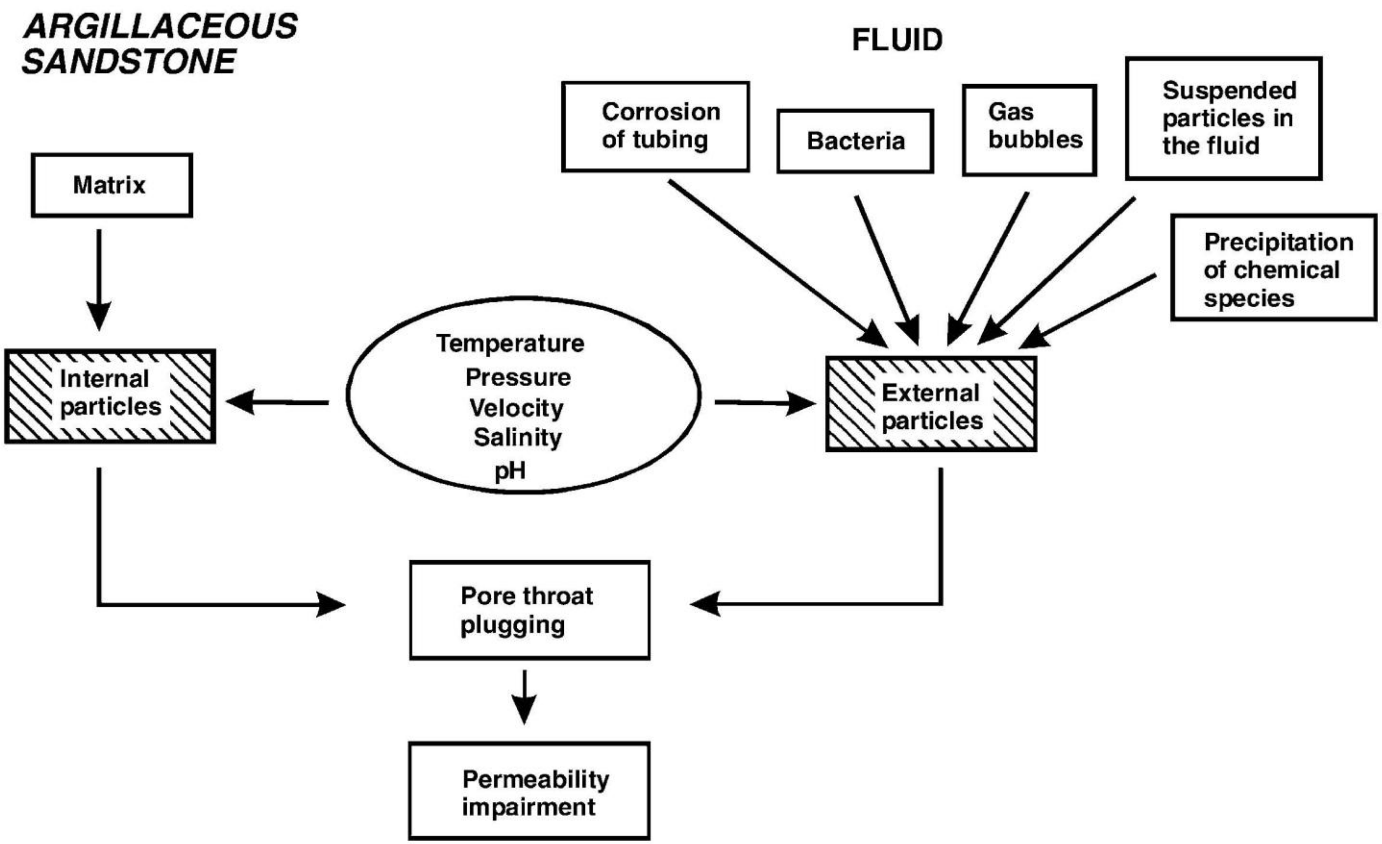
ANTI-CORROSION WELL COMPLETION



SOLUTION GASES
GAS ABATEMENT LINE

WATER INJECTION
MEDIUM AND LOW ENTHALPY RESERVOIR ENVIRONMENTS

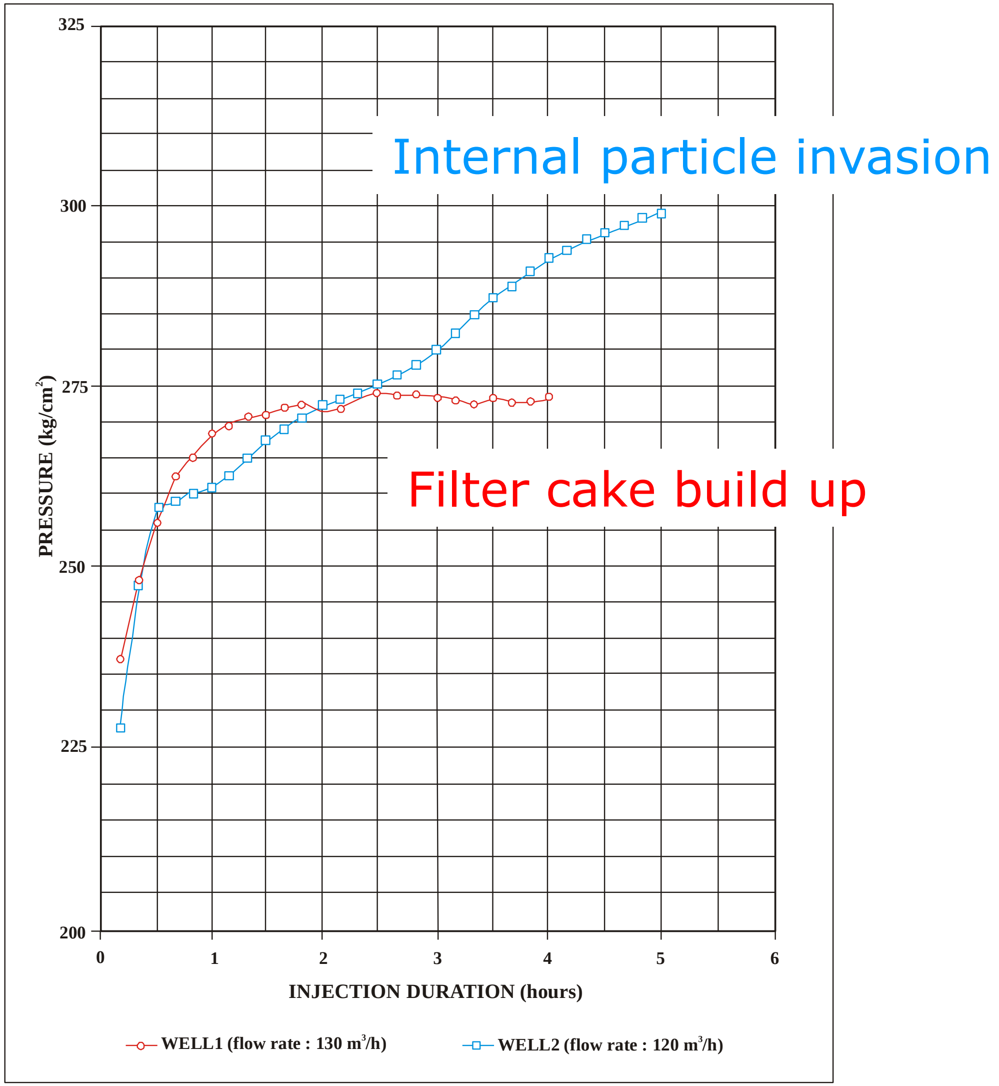
- Permeability impairment



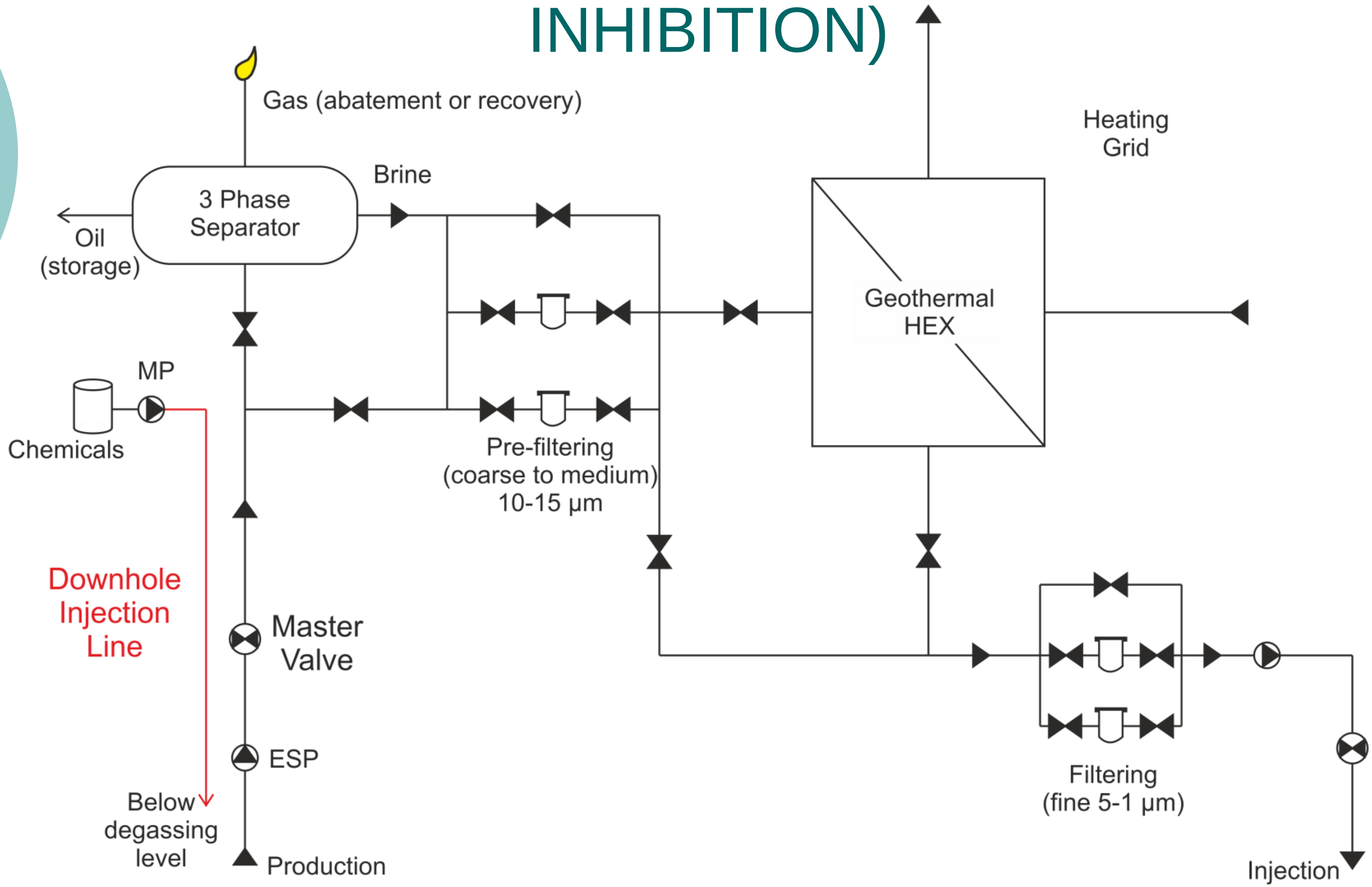
Permeability impairment induced by particles [European Commission, 1997]

WATER INJECTION

PARTICLE INDUCED DAMAGE



GEOTHERMAL BRINE PROCESSING (3 PHASE SEPARATION, 2 STAGE FILTERING, DOWNHOLE CHEMICAL INHIBITION)



PROBLEM AREAS
THERMOCHEMICAL SHORTCOMINGS

CORROSION AND SCALING
DRIVING MECHANISMS OF CASING DAMAGE
AQUEOUS CO2/H2S ENVIRONMENT

Chemical reaction:

$CO_2 + H_2O \rightarrow H_2CO_3$

$2H_2CO_3 \rightarrow 2H^+ + 2HCO_3^-$

$Fe^{2+} + 2HCO_3^- + 2H^+ \rightarrow 2H^+ + Fe(HCO)_2$ soluble

$H_2S + H_2O \rightarrow H^+ + HS^- + H_2O$

$Fe \rightarrow Fe^{2+} + 2e^-$

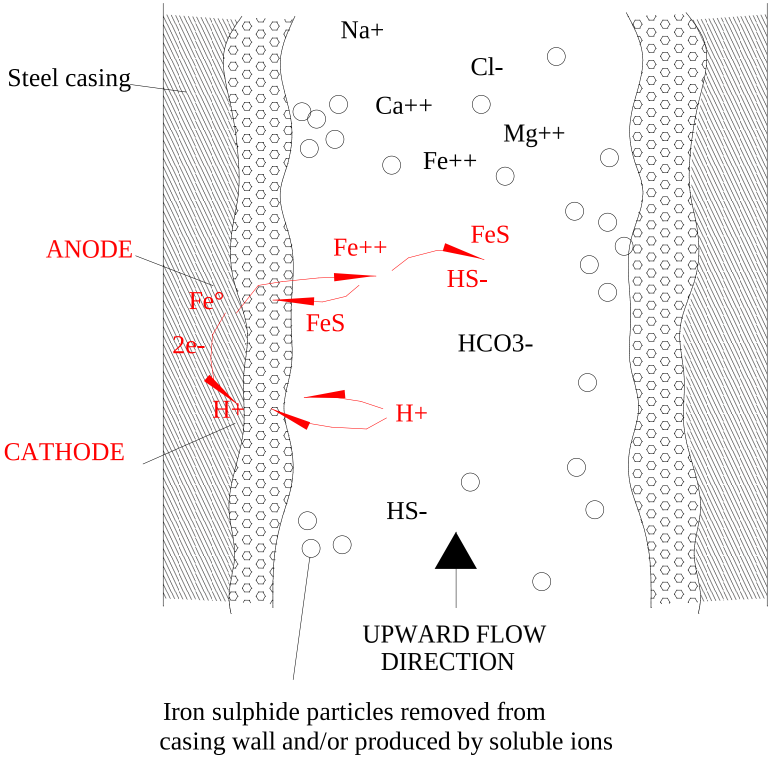
$Fe^{2+} + HS^- \rightarrow FeS + H^+$

Corrosion induced and native

$2\,H^+ + 2e^- \rightarrow H_2$

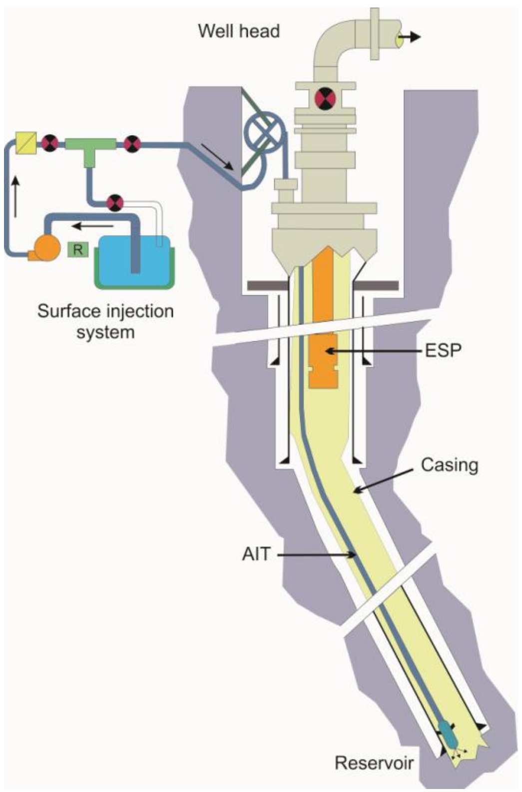
for pH = 6

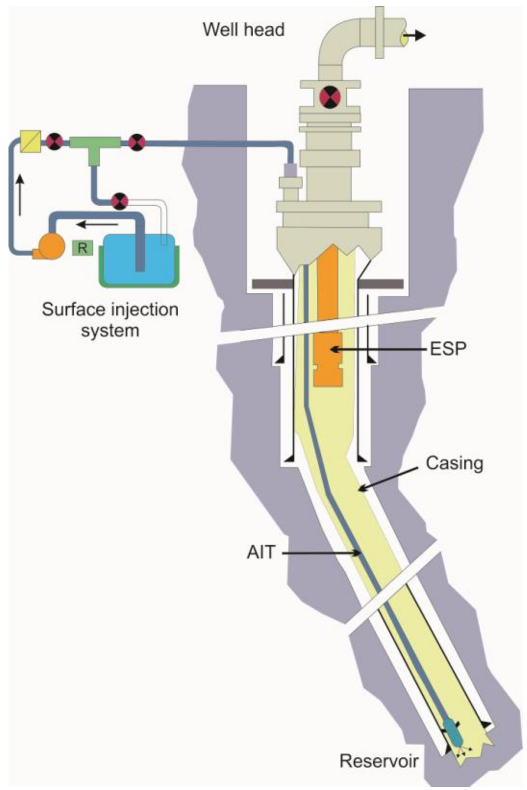
$H_2S + H_2O + CO_2 + Fe^{2+}$ (native)

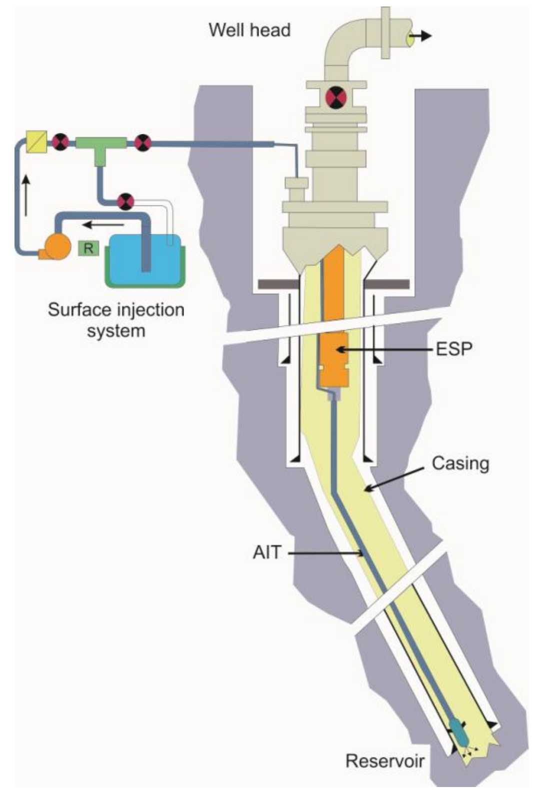


THERMOCHEMISTRY

DOWNHOLE CORROSION/SCALING INHIBITION AUXILIARY INJECTION TUBING (AIT) SET UP

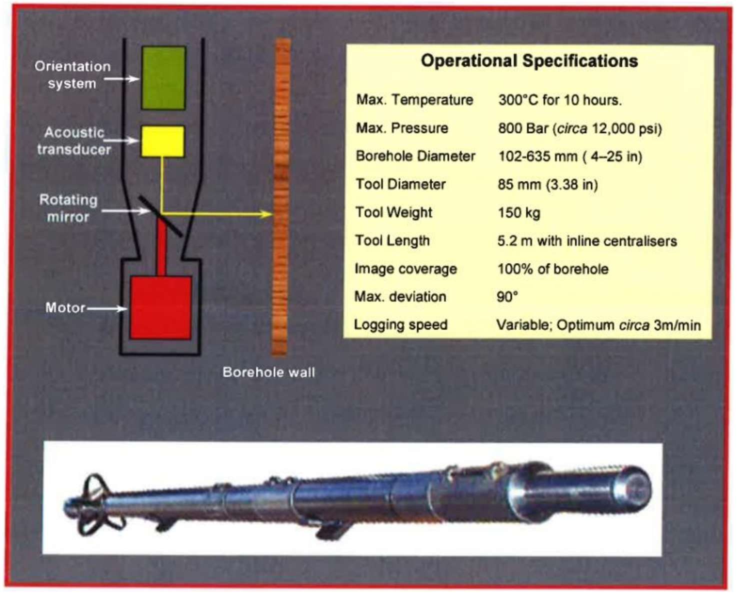




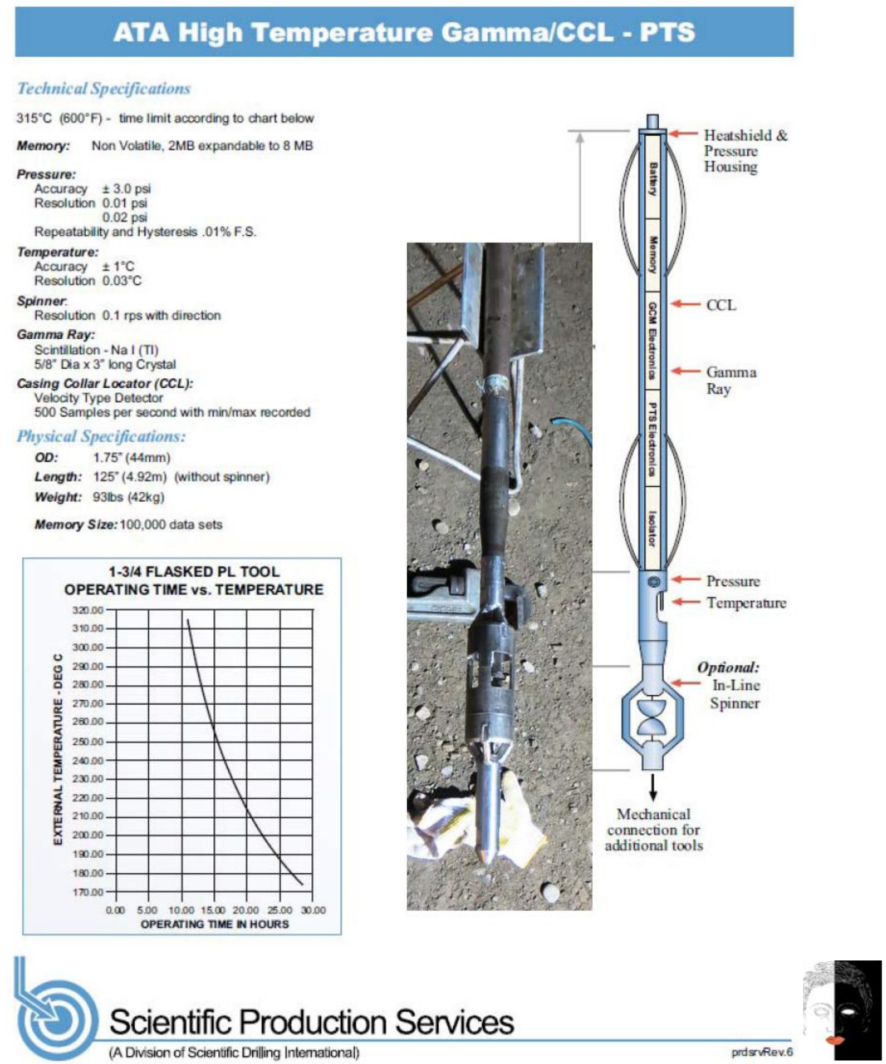


HIGH TEMPERATURE OPENHOLE LOGGING

- Acoustic Borehole Imager (ABI) / televiewer (AFIT)
  - •Tool description & performance
  - •Combined production logging tool



Source: ALT (2013) & Tiger Energy Services (2013)


ATA High Temperature Gamma/CCL - PTS

Technical Specifications

315°C (600°F) - time limit according to chart below

Memory: Non Volatile, 2MB expandable to 8 MB

Pressure:
Accuracy ± 3.0 psi
Resolution 0.01 psi
0.02 psi
Repeatability and Hysteresis .01% F.S.

Temperature:
Accuracy ± 1°C
Resolution 0.03°C

Spinner:
Resolution 0.1 rps with direction

Gamma Ray:
Scintillation - Na I (Tl)
5/8" Dia x 3" long Crystal

Casing Collar Locator (CCL):
Velocity Type Detector
500 Samples per second with min/max recorded

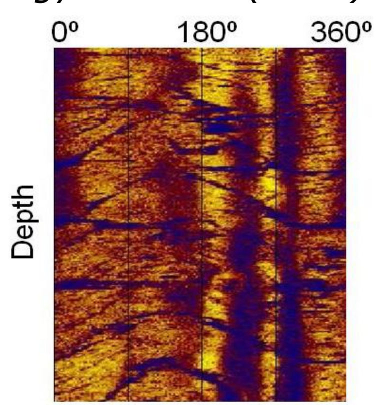
Physical Specifications:

OD: 1.75" (44mm)
Length: 125" (4.92m) (without spinner)
Weight: 93lbs (42kg)

Memory Size: 100,000 data sets

Scientific Production Services
(A Division of Scientific Drilling International)
prdsrvRev.6

- •Borehole televiewer amplitude imaging



Source: MC Lean & Mc Namara (2011)

HIGH TEMPERATURE PUMPING SERVICES

ENCLOSED LINESHAFT PUMP (ELSP)

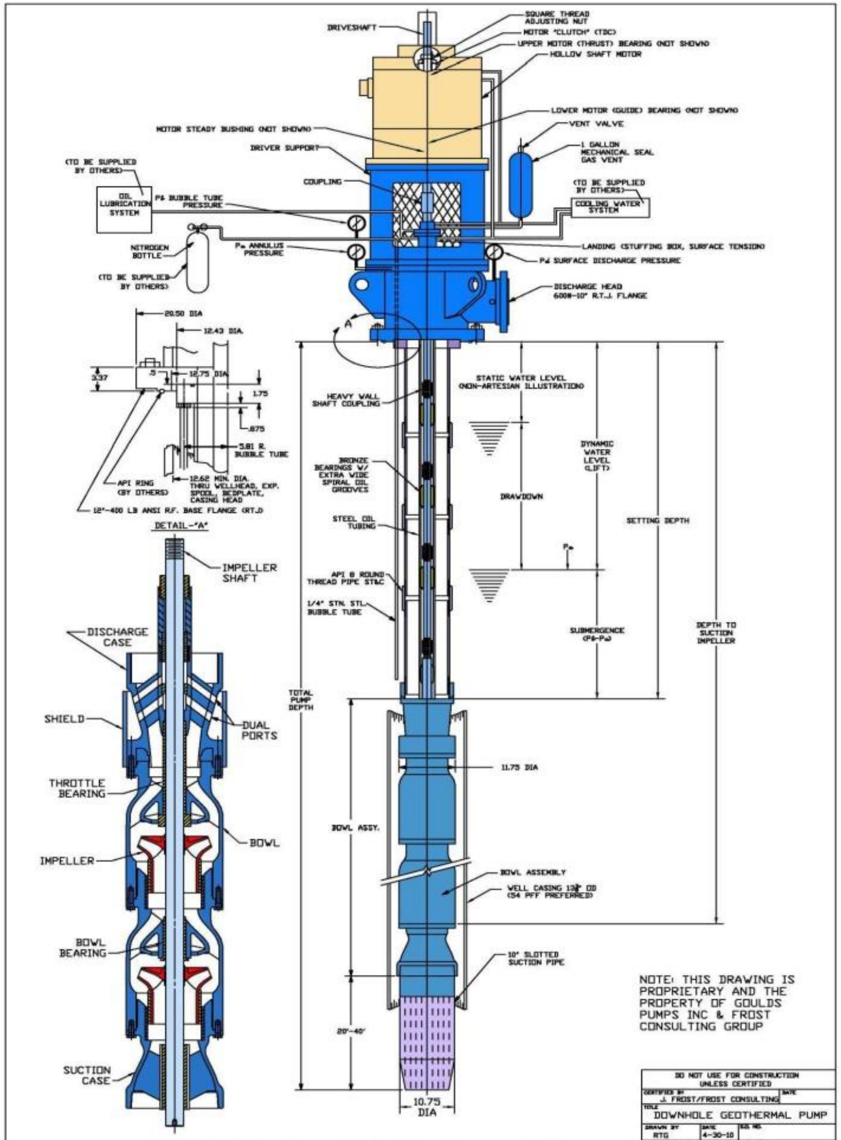


FIGURE 1: Downhole Geothermal Pump

Source: Jack Frost (2013)

HIGH TEMPERATURE PUMPING SERVICES

SCHLUMBERGER (REDA) ESP HOT LINE 550 SERIES (@ 220°C)

Online=250°C for Hot Line 3

Objective=300°C (US DOE EGS Programme)

APPLICATIONS

- Wells with high bottomhole temperatures
  - Steamflooding and thermal recovery applications
  - Geothermal applications
  - Poorly cooled motors in viscous applications
  - Wells with low flow rates
- Wells with abrasive fluids
- Gassy wells
- Wells with corrosive fluids, including H_2S, CO_2, and chemical treatments

ADVANTAGES

- Extended ESP run life in severe applications
- Expanded ESP operating range
- Increased production in thermal recovery applications

FEATURES

- Motor insulation system rated up to 288 degC [550 degF]
- Capability of withstanding severe heating and cooling cycles
- Nonelastomeric seal at pothead
- Expanded oil reservoir for extra cooling capacity with integral oil filter

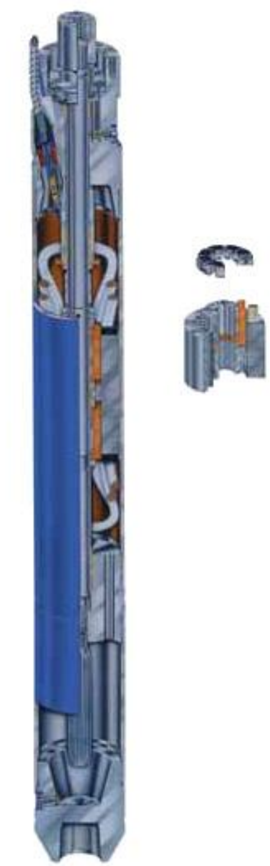
REDA* Hotline* high-temperature ESP motors are designed for extreme conditions. They operate reliably in extremely high temperatures that are common to thermal recovery heavy oil production systems, such as steam-assisted gravity drainage (SAGD) and other steamflooding applications. Motors have a three-phase squirrel cage, two-pole induction design much like that of standard ESP motors. Hotline motors, however, are designed to handle the wide temperature variations that result with cool surface temperatures and extremely hot downhole operating temperatures.

The high-temperature design allows for increased starting torque and greater efficiency. The steel stator laminations focus the magnetic forces on the rotors to reduce energy loss. The stator windings have added copper fill and a proprietary high-temperature insulation system. Hotline ESP motors use a special motor pothead specifically designed to withstand thermal shock. The pothead has a highly reliable tape-in connection and metal-to-metal seals to act as a barrier to fluid entry. The motors use special high-temperature dielectric oils and bearing systems to ensure that lubricity and load requirements are met in high-temperature operating conditions. They also have a large oil reservoir in the motor base to allow the oil to expand and contract with wide thermal cycles and a filter to eliminate debris.

Specifications

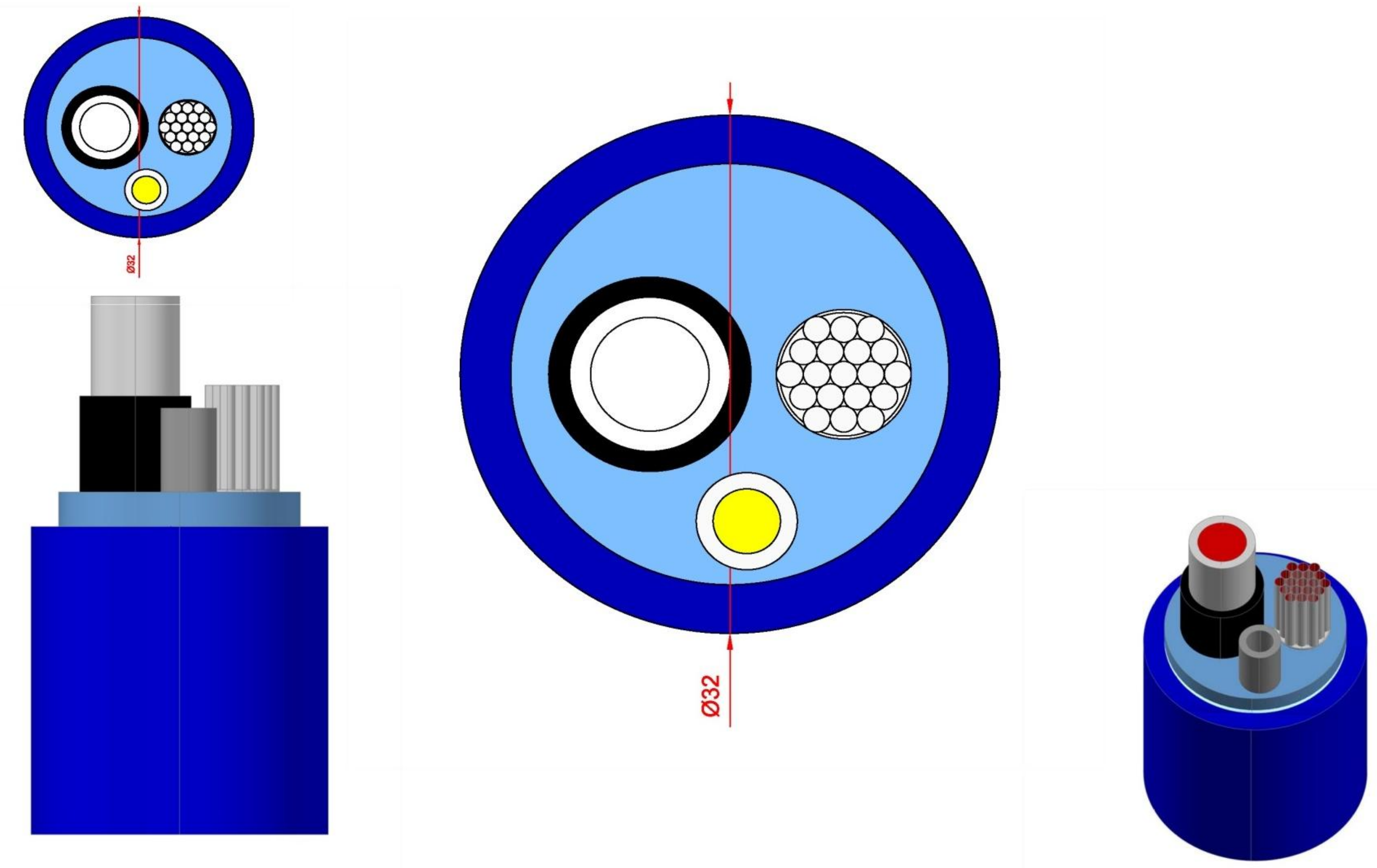
Series	562
Motor OD, mm [in]	142.75 [5.62]
Min. casing ID, mm [in]	177.8 [7.0]
Max. motor winding temperature, degC [degF]	288 [550]
Max. bottomhole temperature,† degC [degF]	218 [425]
Min. power at 60 Hz, hp	42.8
Min. power at 50 Hz, hp	35.7
Max. power at 60 Hz,‡ hp	321
Max. power at 50 Hz,‡ hp	267

† For REDA Hotline550* ESP motor.
‡ Single section.

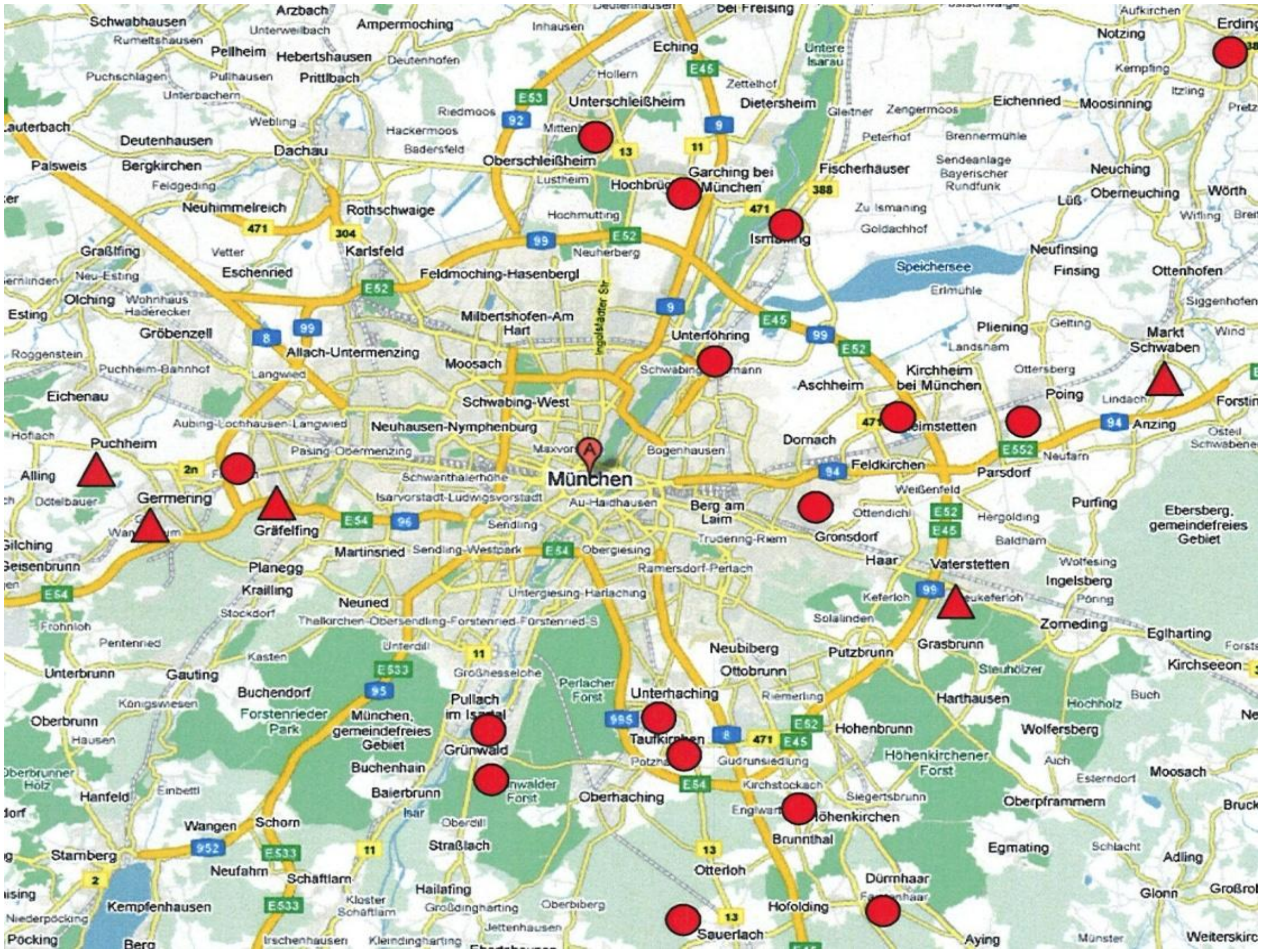


REDA Hotline550 ESP motor with stator, windings, copper fill, and high-temperature insulation.

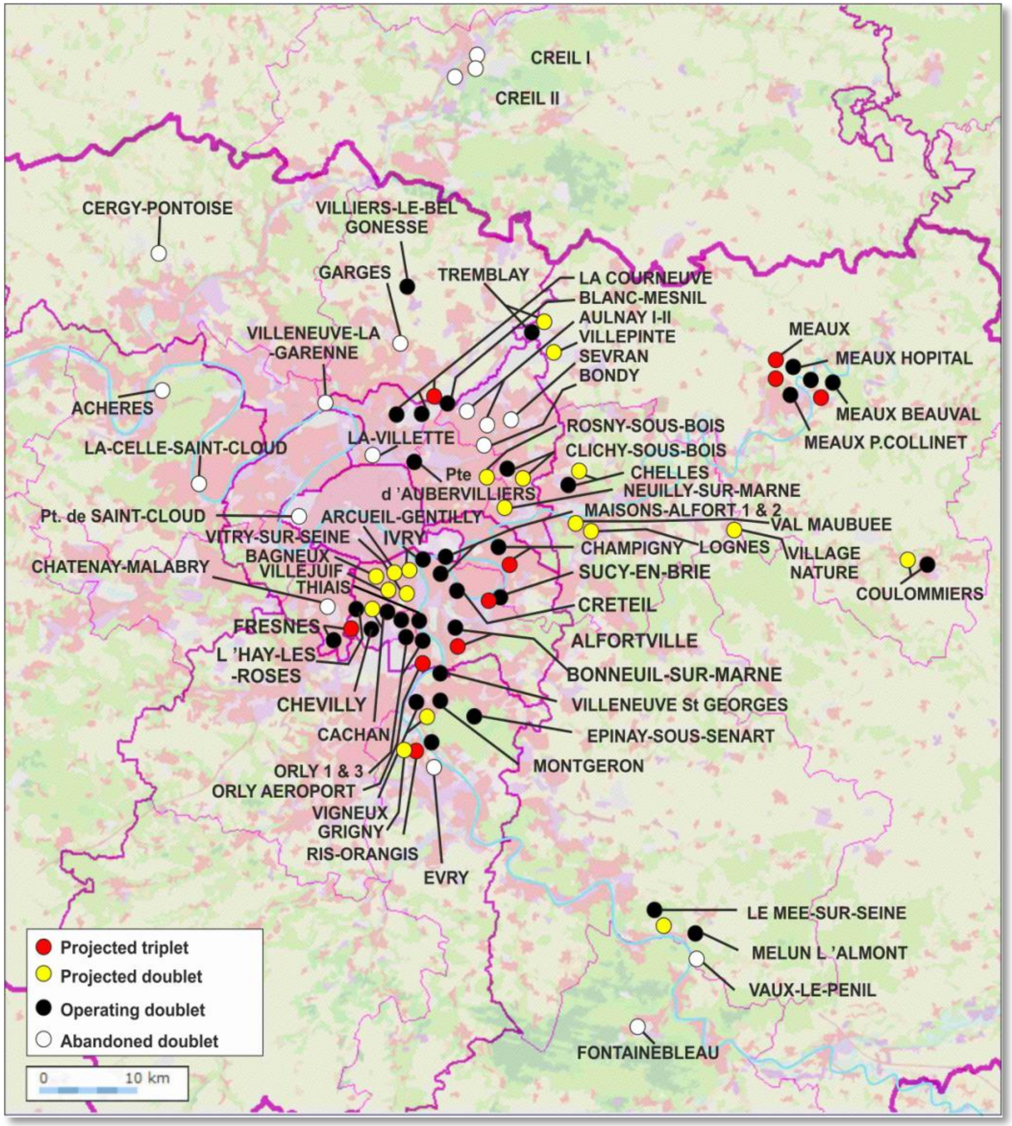
INNOVATIVE DOWNHOLE CHEMICAL INJECTION/OPTICAL FIBER CONTROL LINE



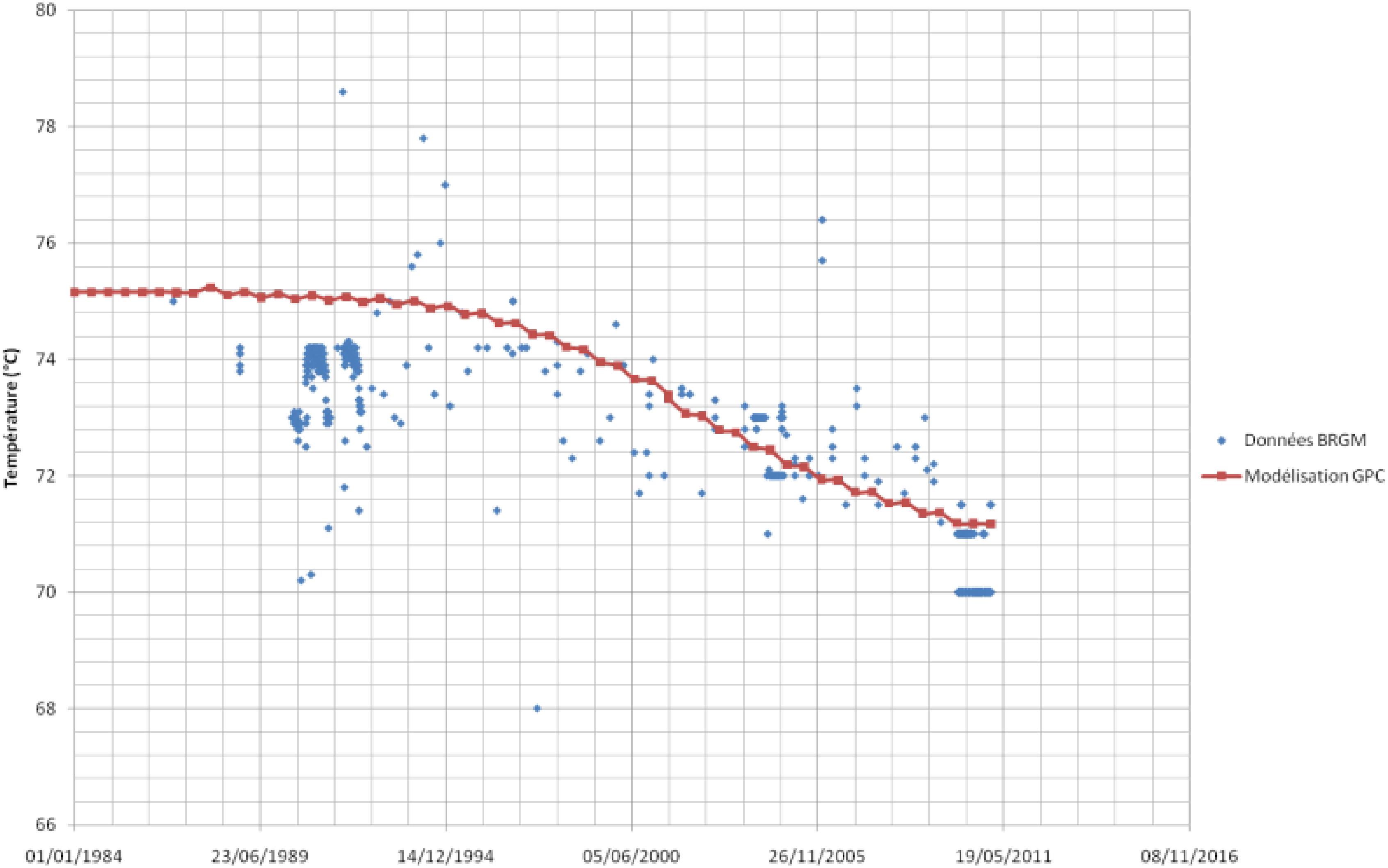
SUSTAINABILITY
MOLASSE BASIN



SUSTAINABILITY
PARIS BASIN

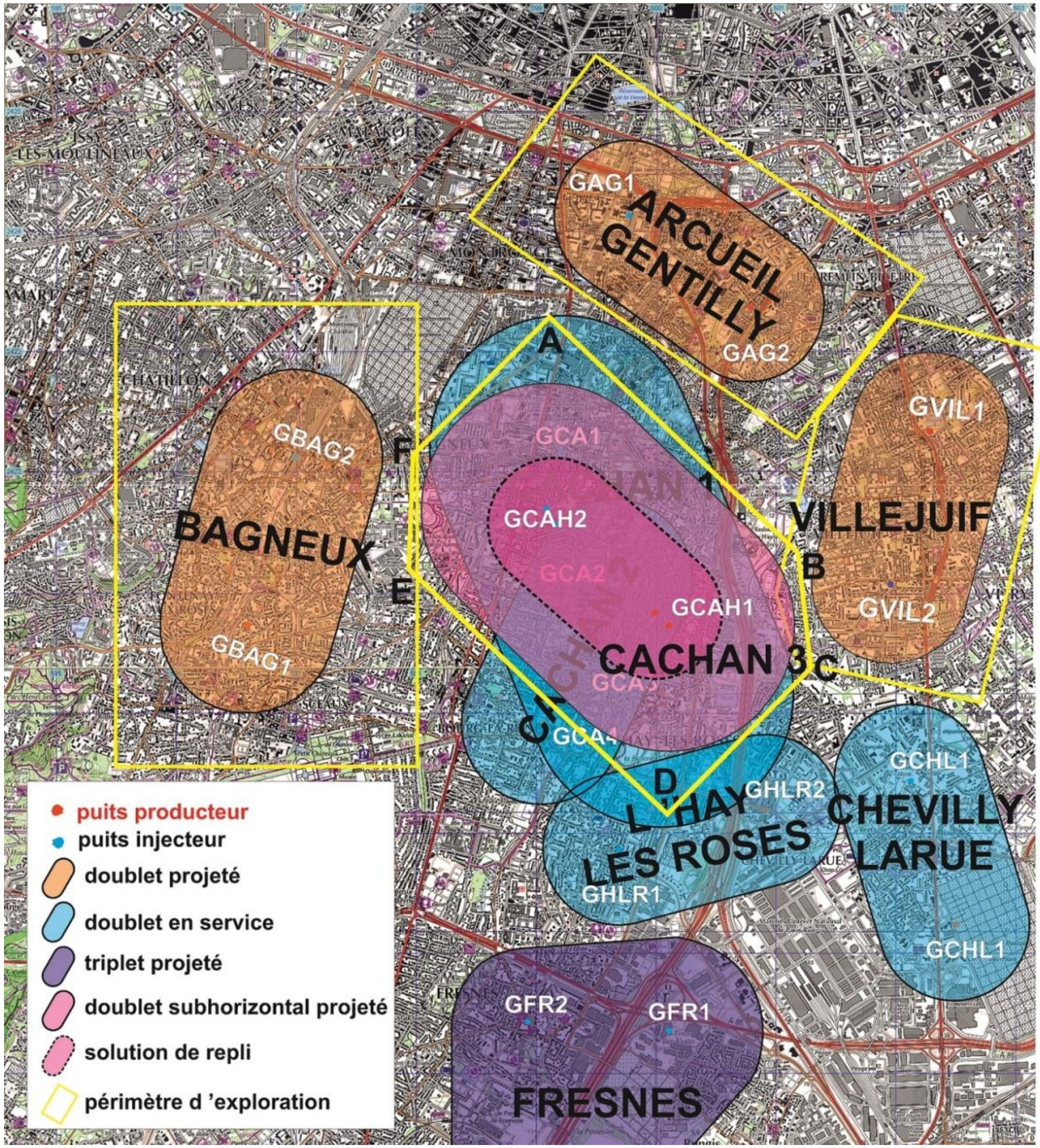


SUSTAINABILITY. RESERVOIR LIFE THERMAL BREAKTHROUGH IS NOT A FICTION. MODELLED VS ACTUAL THERMAL DECLINE



SUSTAINABILITY
MINING COMPATIBILITIES

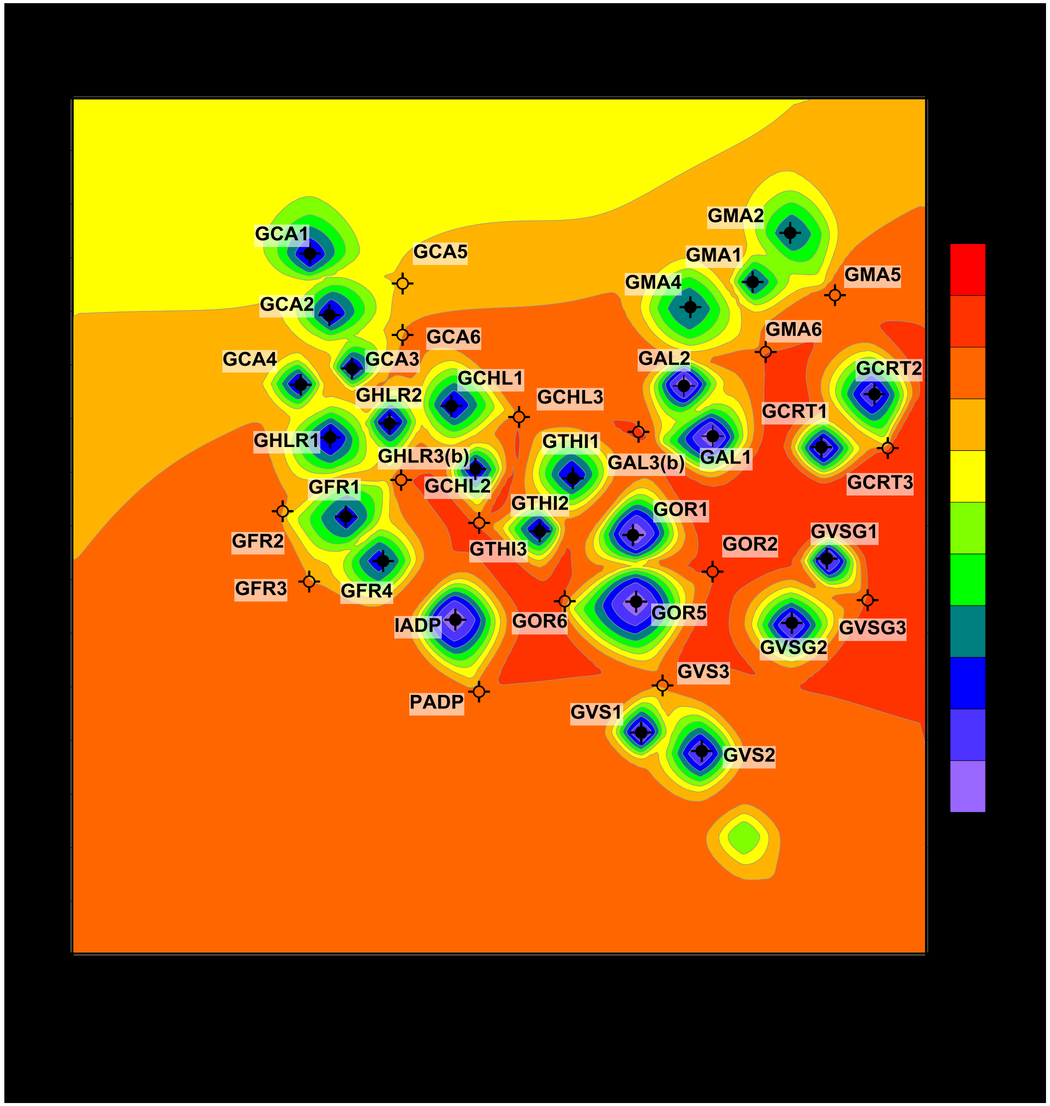
DOUBLET/TRIPLET CONCESSION FOOT PRINTS. PARIS BASIN



SUSTAINABILITY

MULTI-DOUBLET EXPLOITATION (1984-2035)

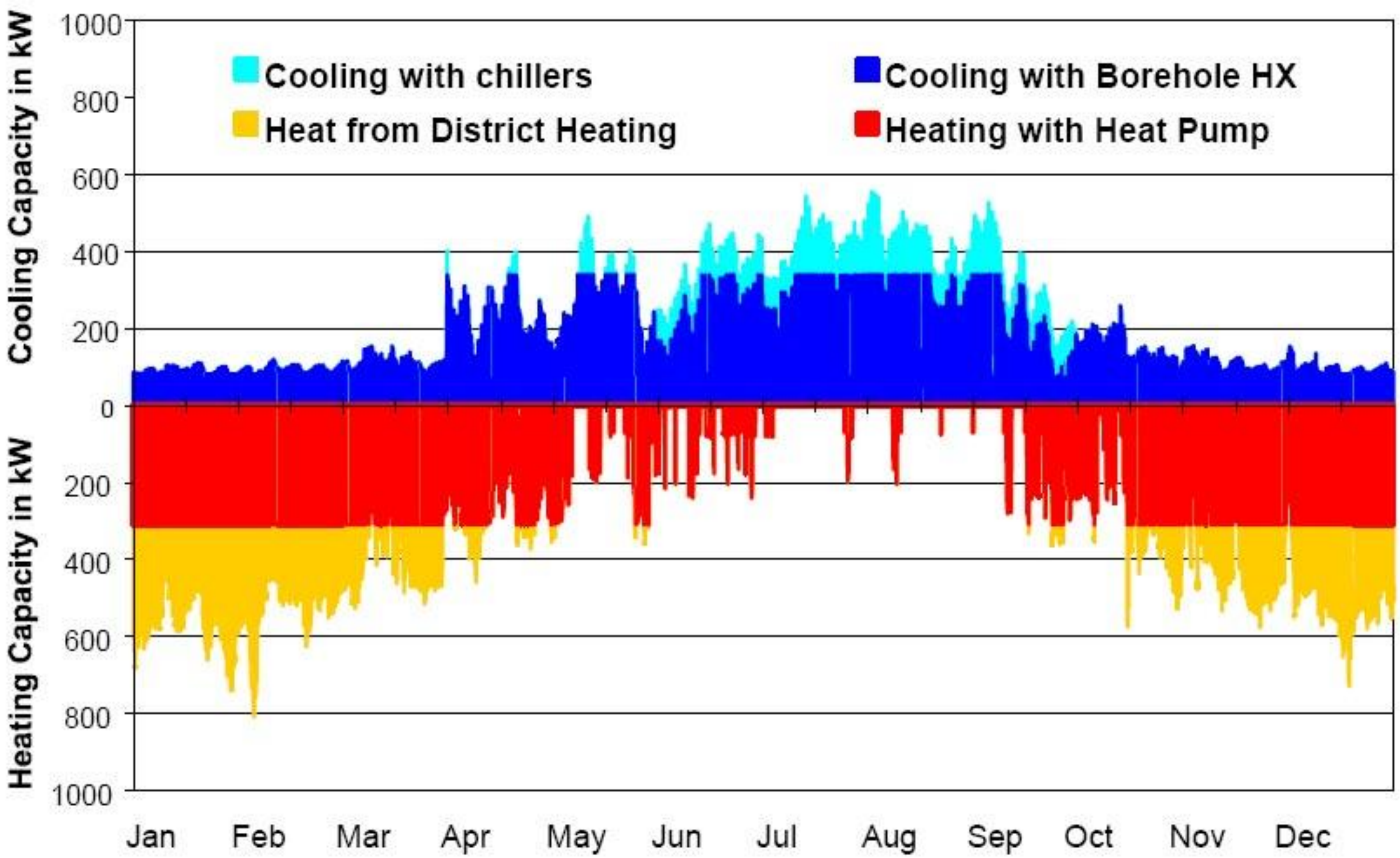
PARIS SOUTH. YEAR 2035



Source : Maria PAPACHRISTOU

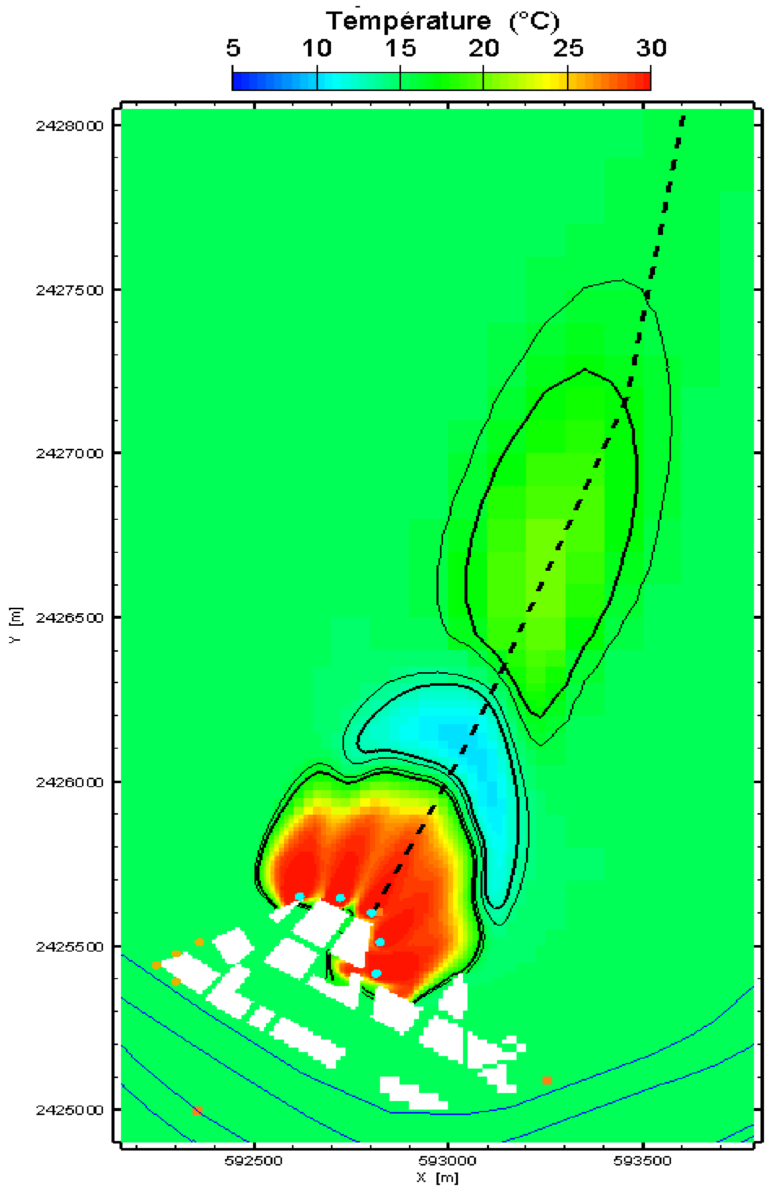
SUSTAINABILITY
BALANCED COLD VS HEAT PRODUCTION

- **GSHP REMEDIAL TO TEMPERATURE DEPLETION**



Source: Sanner, 2008

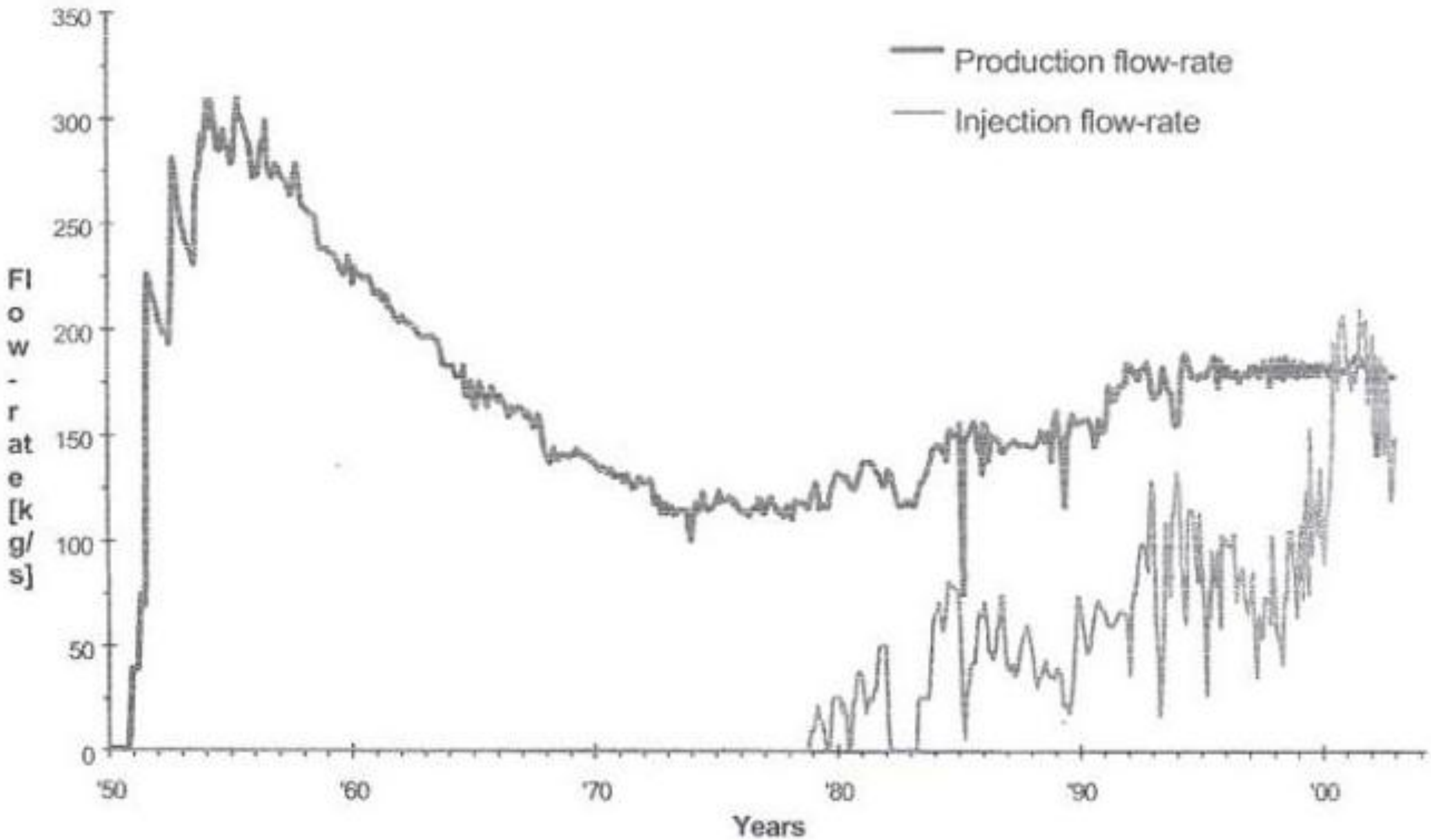
UNBALANCEND COLD VS. HEAT PRODUCTION
EXTENSION OF A HOT PLUME AFTER 17.7 YEARS



SUSTAINABILITY

SUSTAINED STEAM PRODUCTION BY IMPORTED WATER INJECTION

- The Larderello field



Influence of the reinjection on the steam flow rate of 28 wells in the Valle Secolo area, Larderello [Capetti,2004]

SUN RISES BUT NEVER SETS ON GEOTHERMAL ENERGY