A new approach to high temperature sensors and electronics for geothermal drilling

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February 2024

HEPHAE
ENERGY TECHNOLOGY

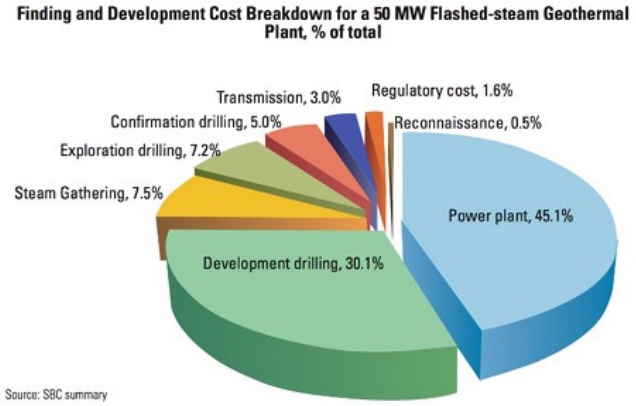
Key Challenges for Geothermal

"the main obstacle to the development of the geothermal sector in Europe remains the high cost of drilling, which represents two thirds of the costs of a geothermal plant"

Briefing for **European Parliament** for Geothermal Energy

"30 to 40 % of Geothermal wells fail to reach their output target. Advances in this area are urgently needed so as to enable market actors to drive down these costs through improved research, industrialisation of the supply chain and more efficient policies and support schemes."

Vittori Prodi
Prof of Physics and former member of European Parliament

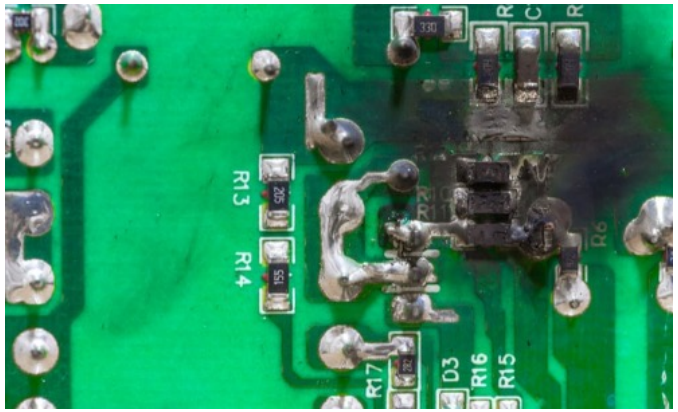


"power generation at lower temperatures is not economical even at lower drilling costs"

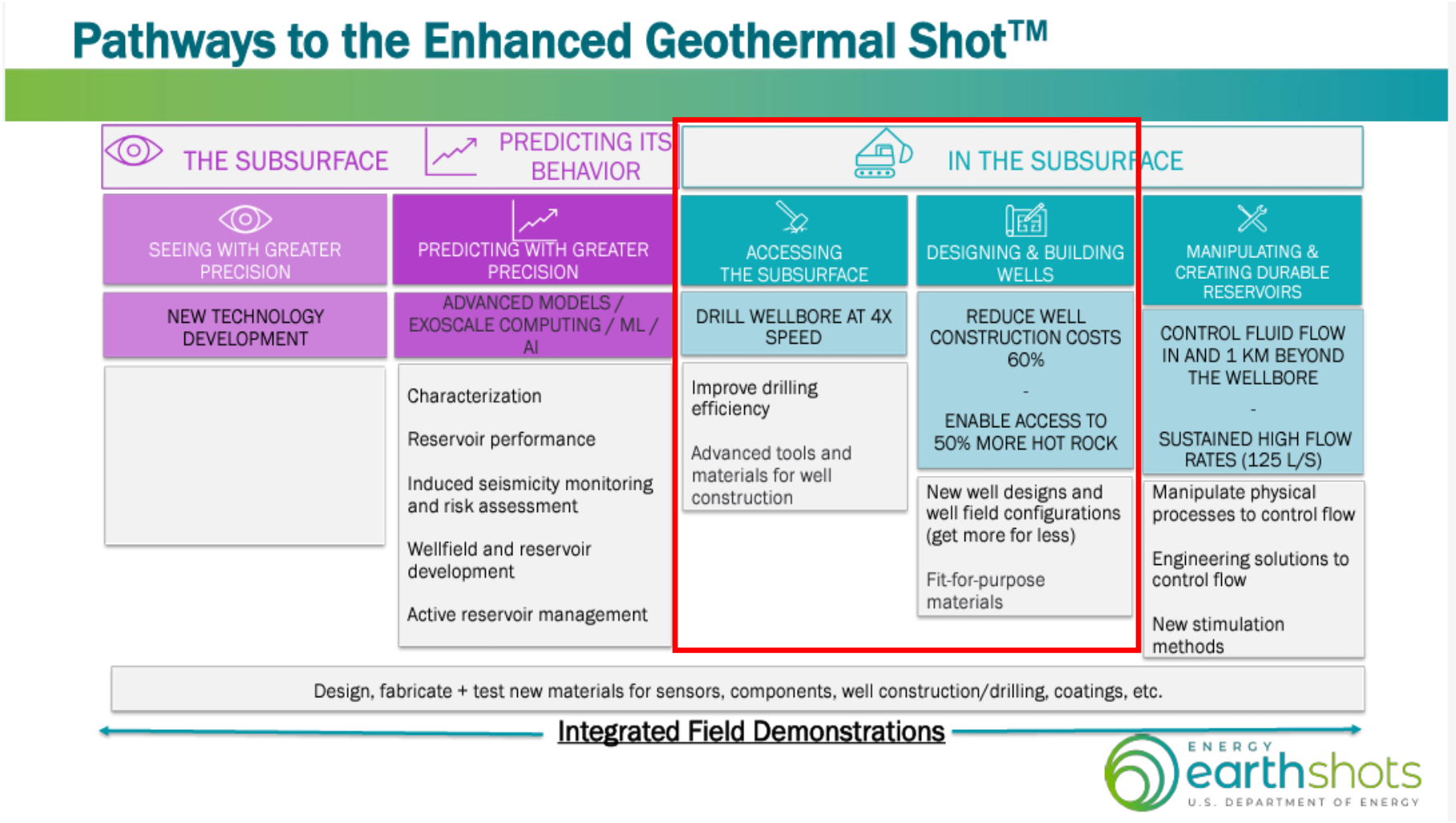
Koenraad Beckers
National Renewable Energy Laboratory

"Most MWD tools are limited to temperatures of up to 180^0 C, as electronic components fail at temperatures above an extended period of $180\ ^0$ C"

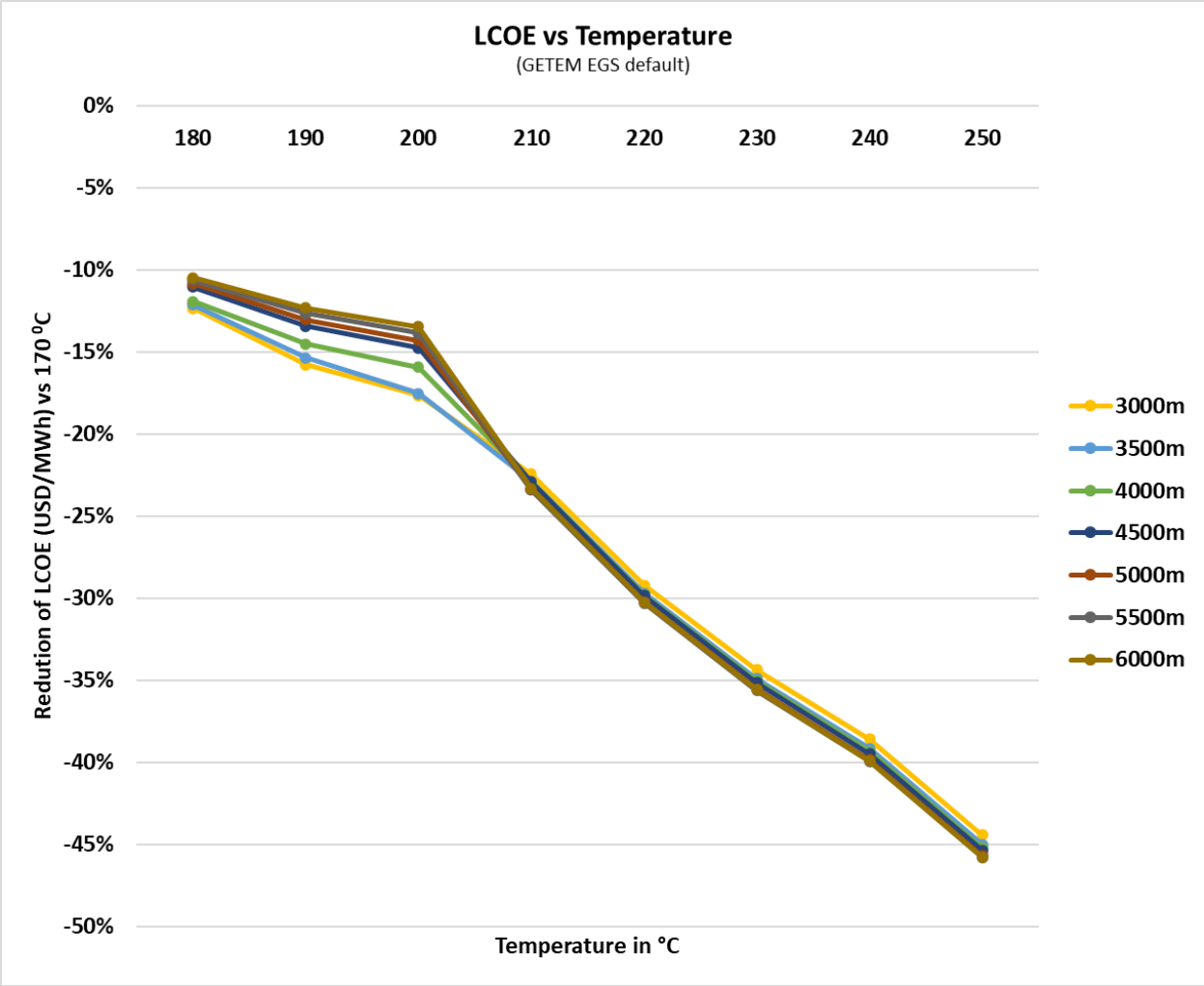
Douglas Blankenship
Sandia National Laboratories



Key Challenges – Earthshot



Key Challenges – Temperature

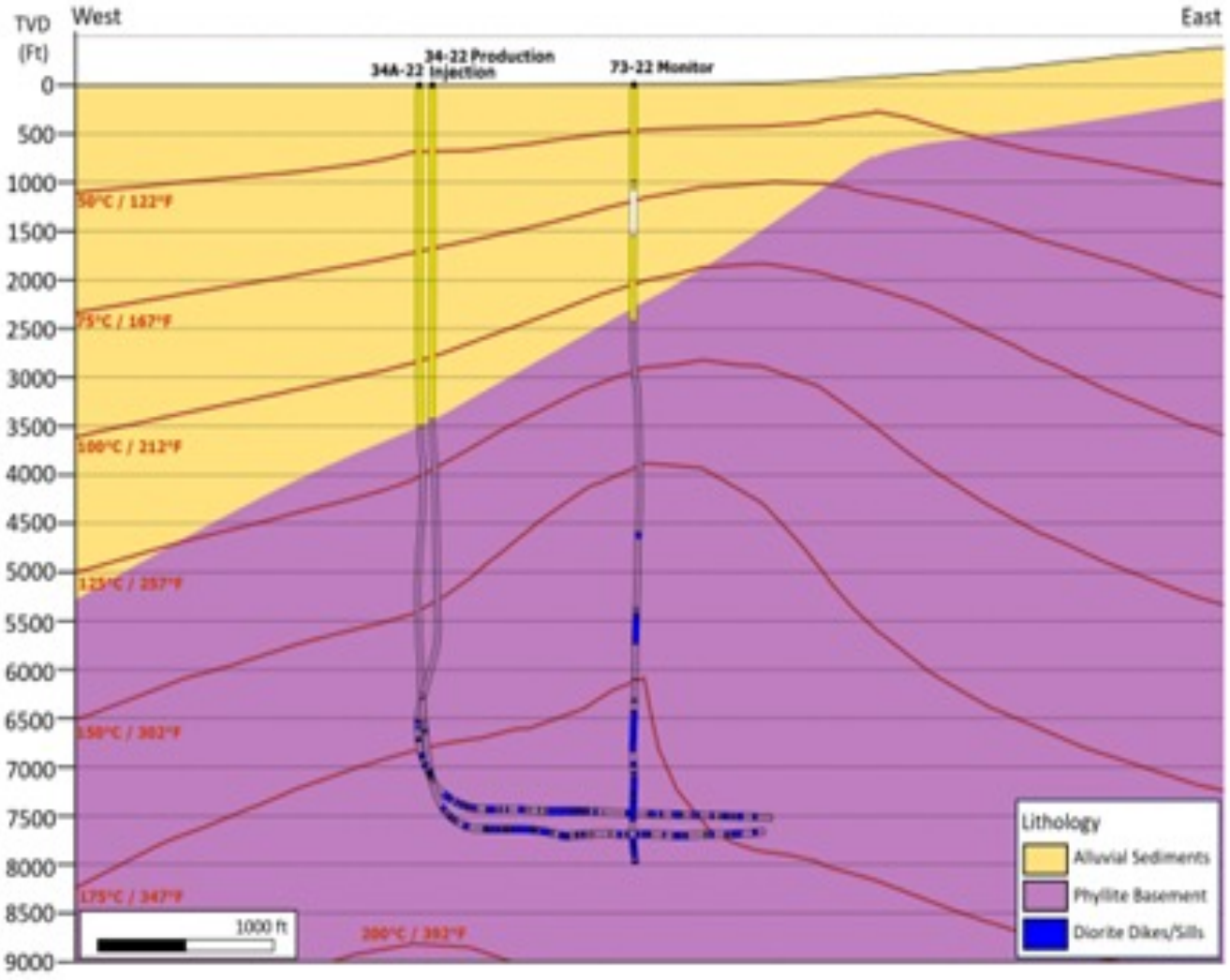


- **Increasing temperature** limitations in drilling tools **to 210^0 C will improve LCOE** over the current status by approximately **25%**
- **Increasing temperature** rating further **to 250^0 C will improve LCOE** over the current status **by approximately 45%**
- Based on Beckers[2] modelling for Eavor Loop 2.0 LCOE improves exponentially between 150%-200% with a bottom hole temperature increase from 235^0 C to 460^0 C in a 7,500 meter deep well

Note 1: Numbers are based on EGS system and derived from the 2016 GETEM model

Note 2: Techno-Economic Performance of Eavor-Loop 2.0, Koenraad F. Beckers, et al.

Fervo Succeeds Using O&G Technology



- Horizontal wells to 7,700 ft 3,250’ horizontal
- This design showed significantly higher flow rates than all previous EGS wells
- The hottest temperature reached was ~190^{0}C
- Provide a peak power production of 3.5 MW
- Now drilling 5000’ horizontals

Drilling Technology Landscape

- Existing MWD/RSS – exists to 175C, small number of tools rated to 200C
- Insulated drill pipe – keeps fluid cooler when circulating but still requires staging in and risks damage if circulation stops
- Esoteric drilling technologies (millimetre wave, plasma, …) – big promise for ultradeep wells once perfected but may still need navigation

- **High temperature MWD/RSS – significant but soluble technical challenges**

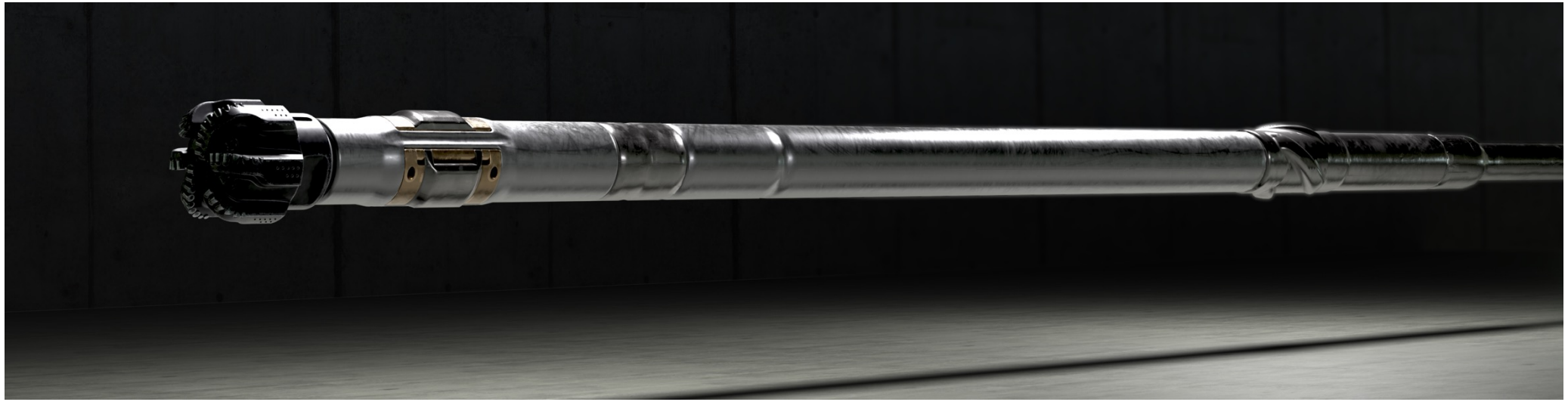
Who are we?

Originally incorporated in in the USA in 2022 and started operation in April 2023. Offices in Bilbao, Cheltenham and Houston.

Mission is to be "*a technology enabler of the Unconventional Geothermal Industry by providing* ***differentiated subsurface drilling technology with significantly extended temperature limits*** *beyond existing capabilities while maintaining the ability to accurately* ***steer complicated wellbores precisely in hotter and deeper wells*** *and thus increasing the potential for greater heat recovery and power generation*."

Strategy is to "**continuously *improve temperature ratings and durability of selected directional drilling technology (tools or components)*** *proven in the unconventional drilling for oil and gas and apply it to Unconventional Geothermal Drilling*".

Addressing the Challenges

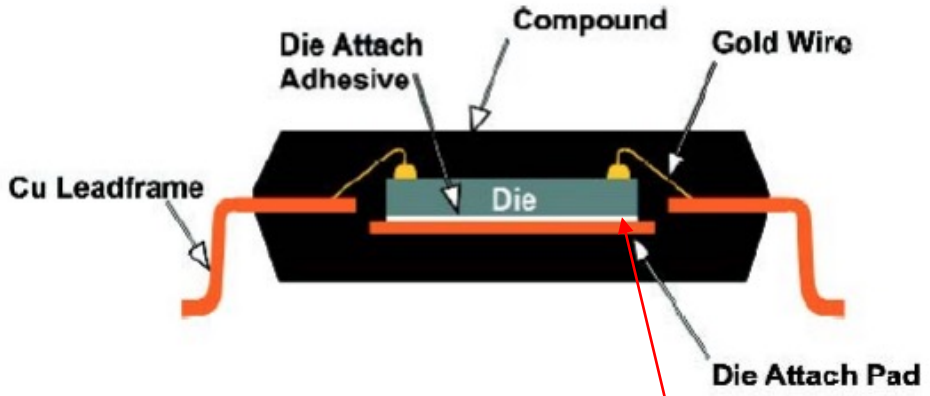


MWD system Pandora210 will initially operate up to **210^{0}C** but with a roadmap to **300^{0}C**

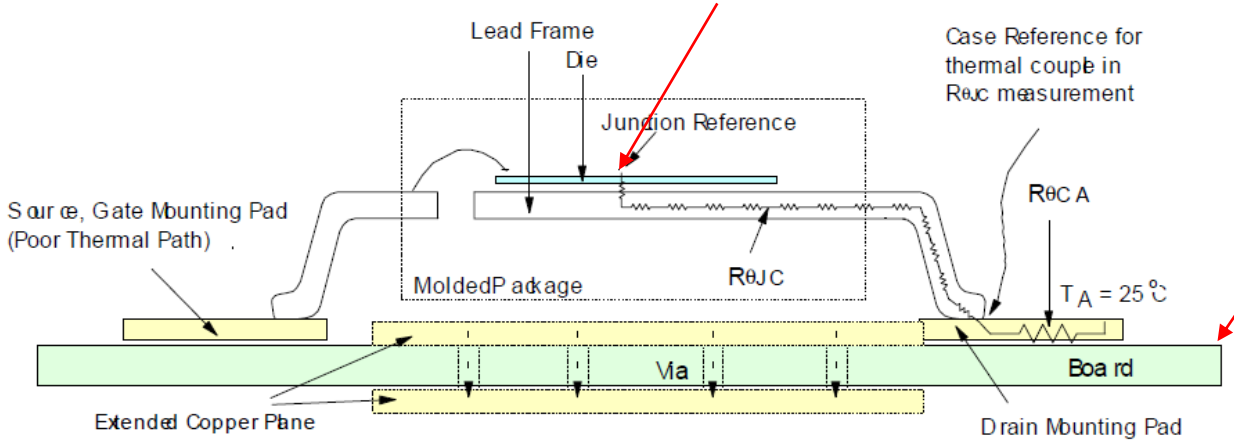
Uniquely, MWD will include an RSS controller which will drive a steering head initially rated to **210^{0}C** and later to **300^{0}C**

- Minimized tortuosity leading to **increased rate of penetration** (ROP) and a reduction of stuck pipe
- **Less tripping and bottom hole equipment handling** and **lower costs** for damaged beyond repair due to higher temperature ratings as well as longer survivability without mud circulation
- **Access to hotter reservoirs** while controlling direction, while maintaining ability to accurately steer

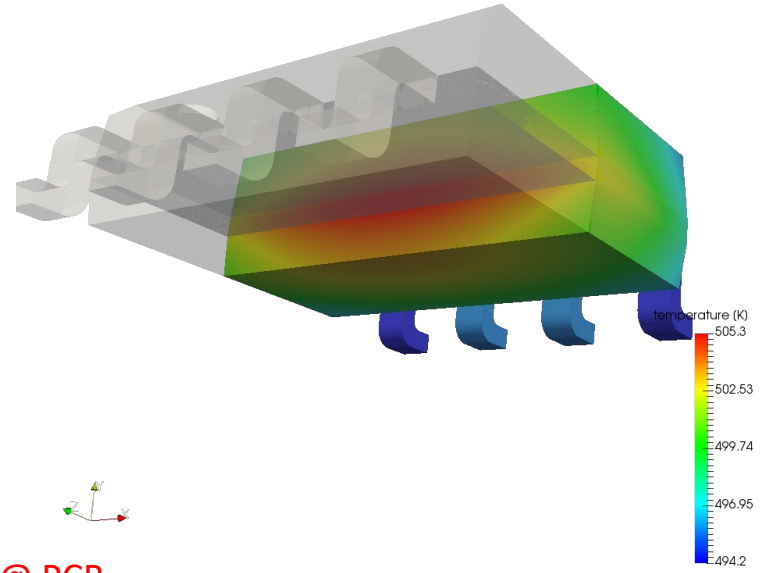
HT Challenge: Keeping the Silicon Cool



Heat Source



Heat Dissipation @ PCB

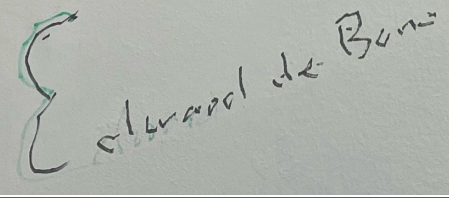


Without solving this, 200C Operating means ~220C Die

Seikolore meetingunea Edward de Bonoren "The Six Thinking Hats" hausnartze paraleloaren teknikan oinarrituta dago.

Seikolore meetingunea está inspirado en la técnica de pensamiento paralelo "The Six Thinking Hats" del profesor Edward de Bono.

"Sometimes the situation is only a problem because it is looked at in a certain way. Looked at in another way, the right course of action may be so obvious that the problem no longer exists."
(Edward de Bono)



How to Get the Heat from Die to Mud?

- Will require multiple complementary techniques
- Use of technologies not available even a few years ago
- Some things I can talk about…
- Some things I can't…

- Board design
- Board packaging
- Heat transfer and direction
- Materials (PCBs)
- Materials (elastomers, metals)

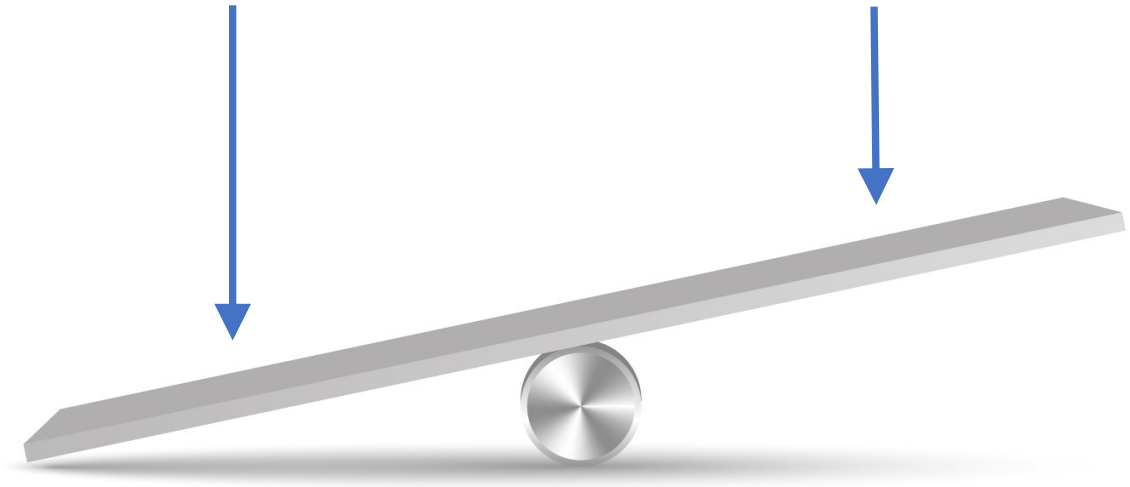
“Conventional” HT MWD/LWD/RSS PCB

IADC/SPE-191054-MS

Balancing Priorities

Shock/vibration
Packaging and volume

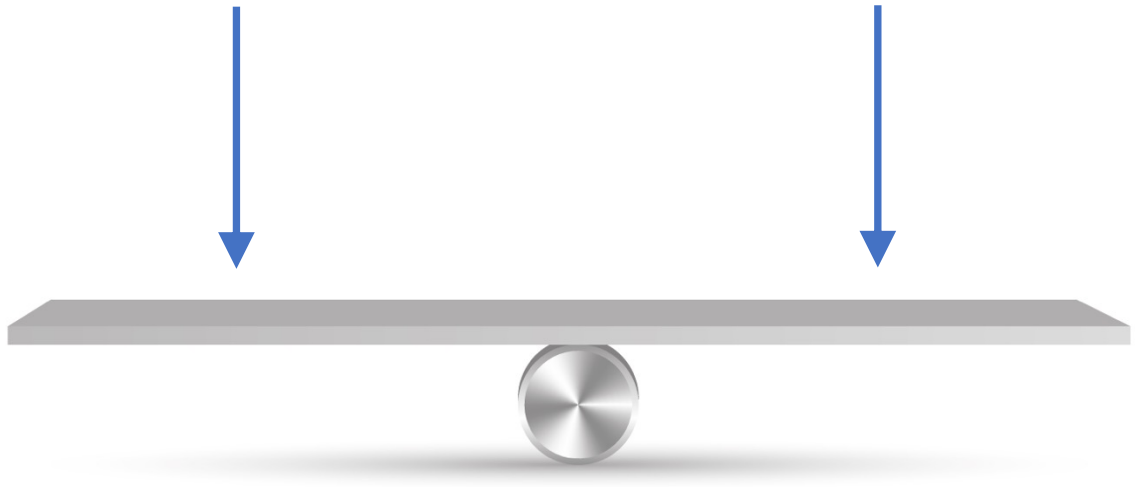
Thermal management



“OLD”

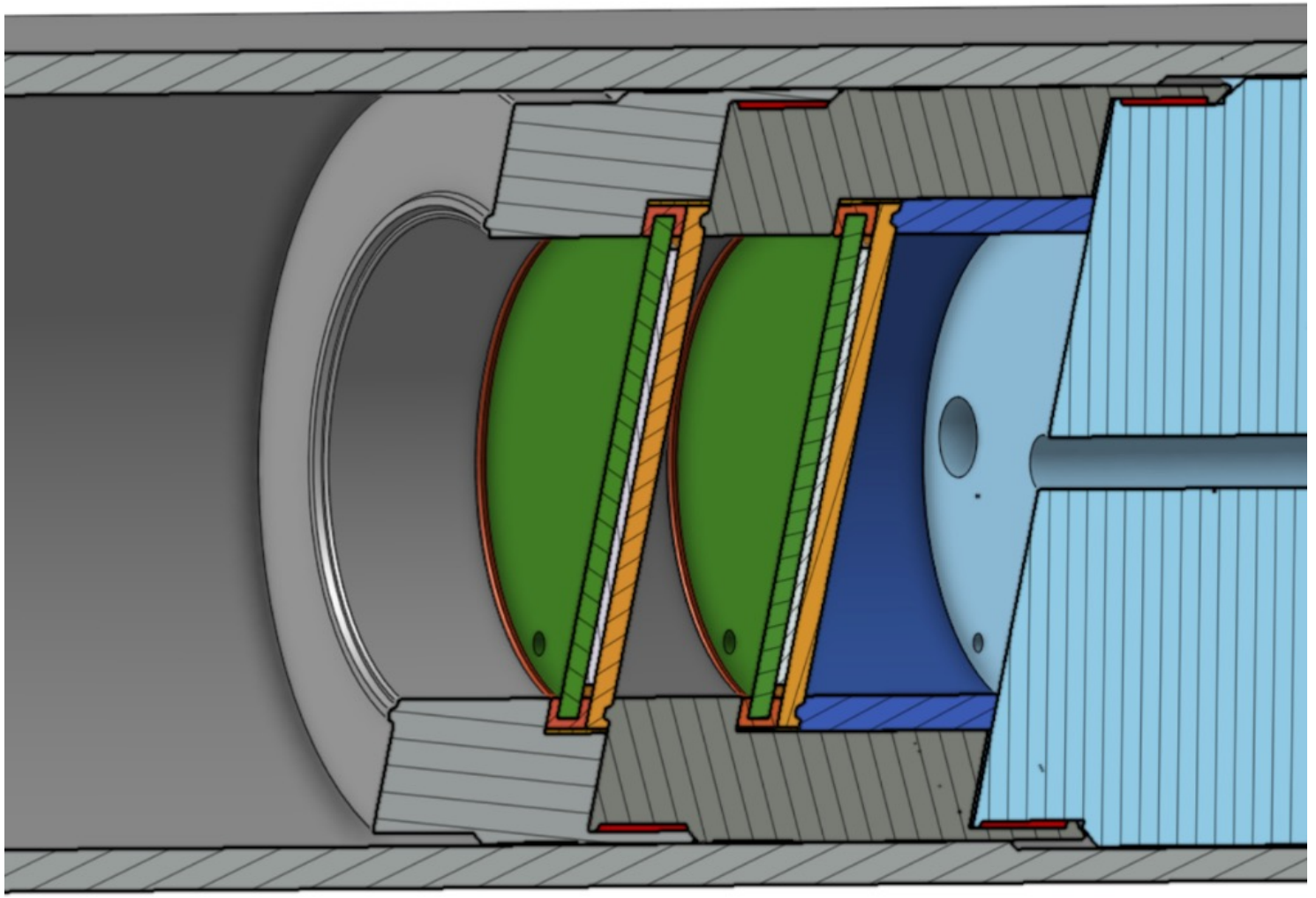
Shock/vibration
Packaging and volume

Thermal management

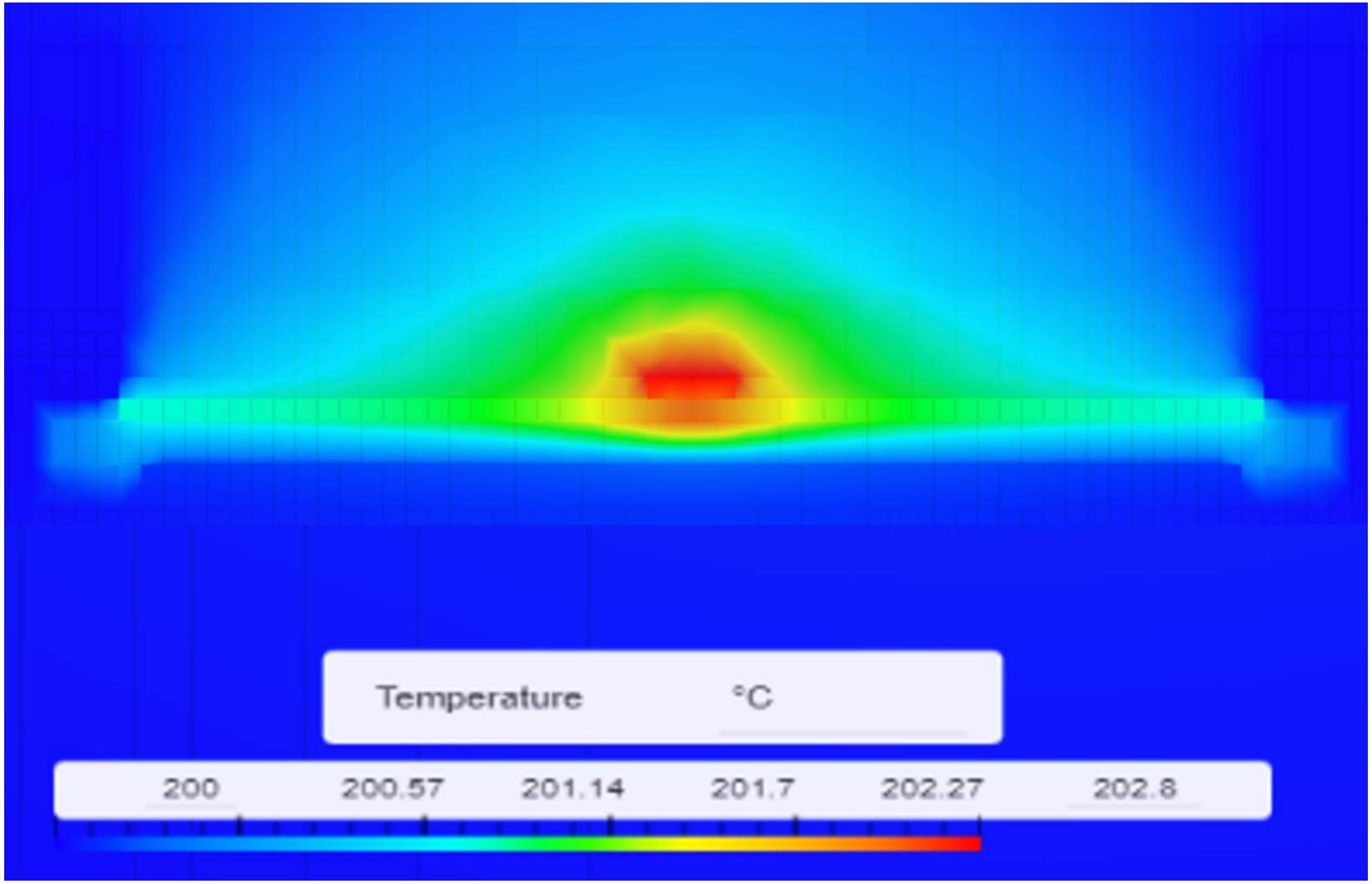


“NEW”

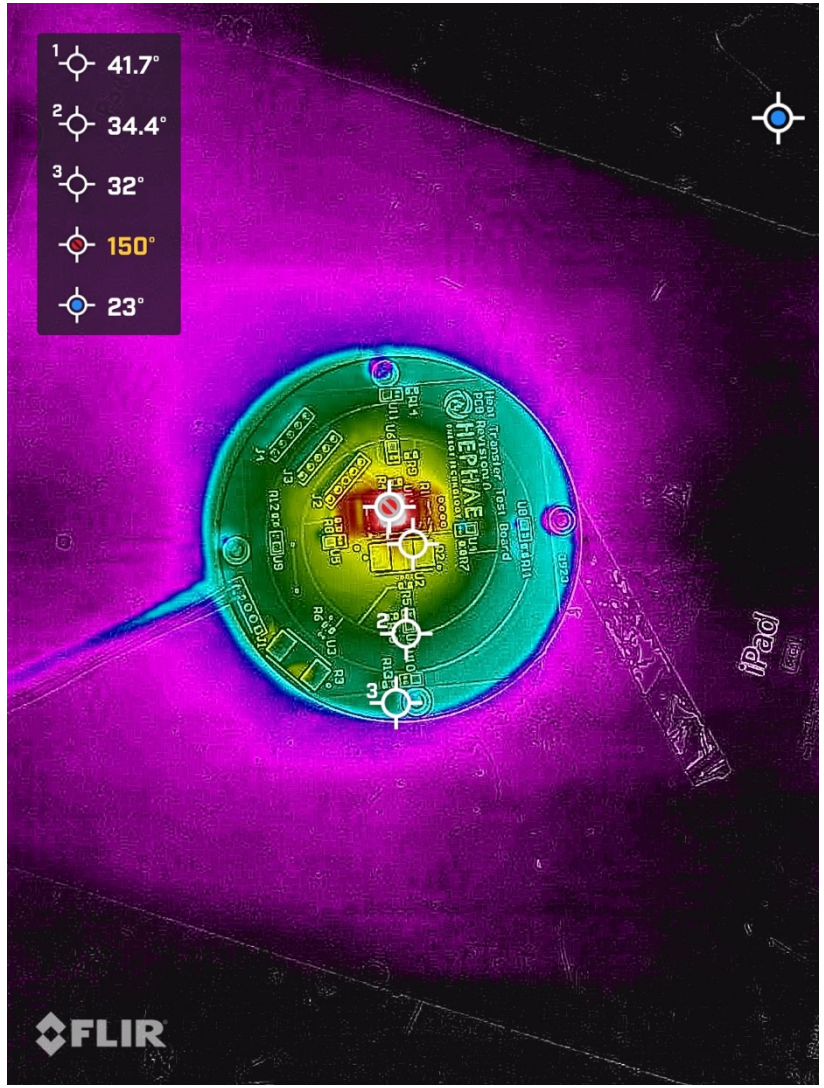
Early PCB Mounting Scheme

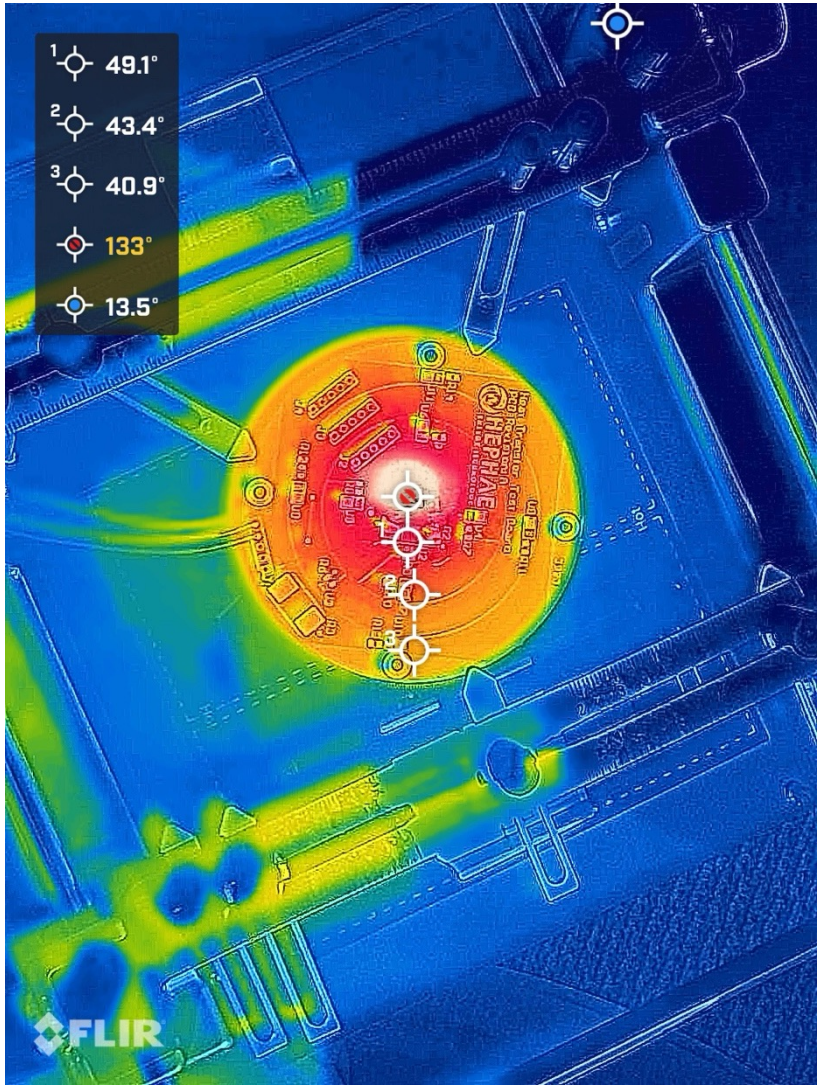


PCB Thermal Model



Heat Dissipation Testing





Sometimes, a new problem needs a new solution

Thank you!

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