

تحت رعاية وزارة النفط والغاز، سلطنة عمان  
HELD UNDER THE AUSPICES OF THE MINISTRY OF OIL AND GAS, SULTANATE OF OMAN

**WORLD  
HEAVY OIL  
CONGRESS & EXHIBITION**

**3-5 September 2018**

Oman Convention & Exhibition Centre  
Muscat, Sultanate of Oman

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شركة تنمية نفط عمان  
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Chief Technology Officer  
Salamander Solutions

**Downhole Heating**  
A New and Robust Re-Creation of a Proven Technology

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## Outline

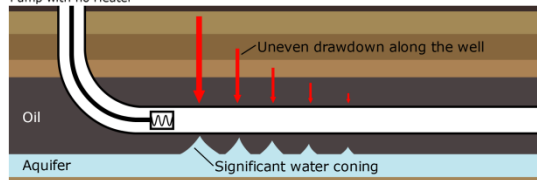
- Origins of Technology
- Commercial Heater
- Technology in Action
  - Deployment in Alberta
- Economics – Customer's Perspective
- Downhole Heater – Other Applications
- Summary

# Heaters in Heavy-Oil Plays

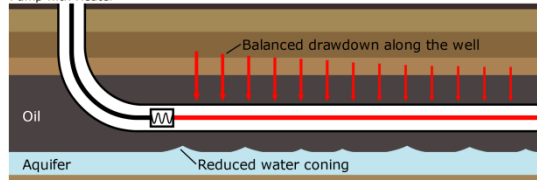
## Thermal viscosity reduction

Benefits of heaters in long laterals

Pump with no Heater

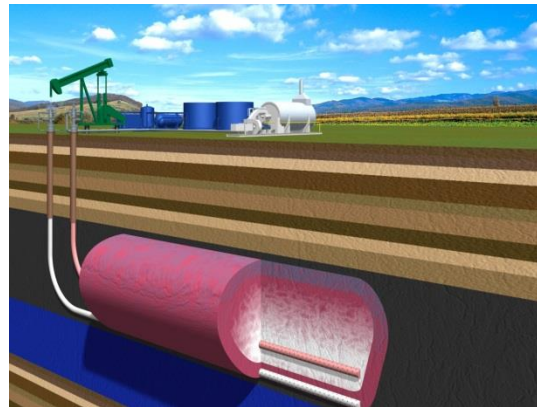


Pump with Heater

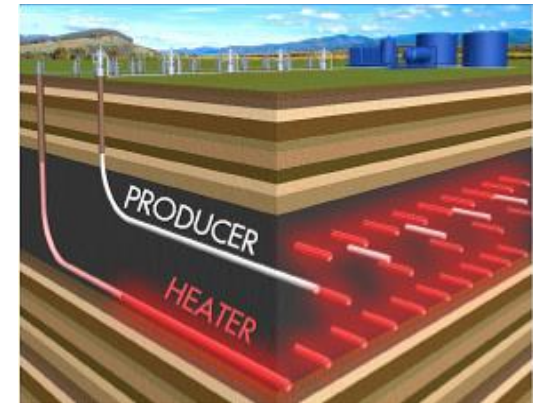


Heating up near wellbore

## SAGD pre-heat



## In-situ Upgrading Process

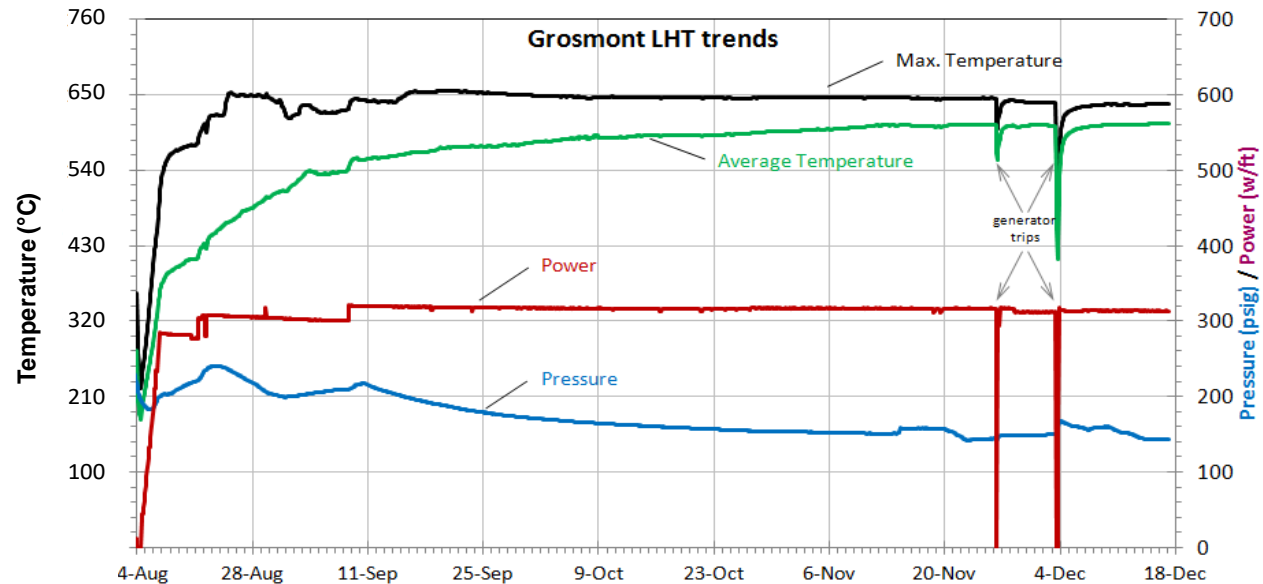
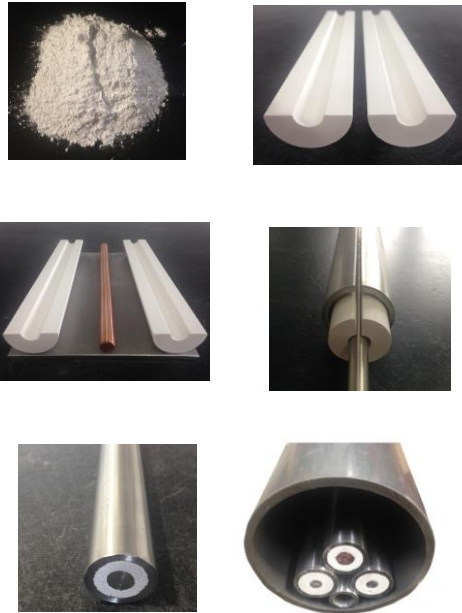


Heating up the entire reservoir

Heat delivery systems

# Commercial Heater

# MI Heater Development Program

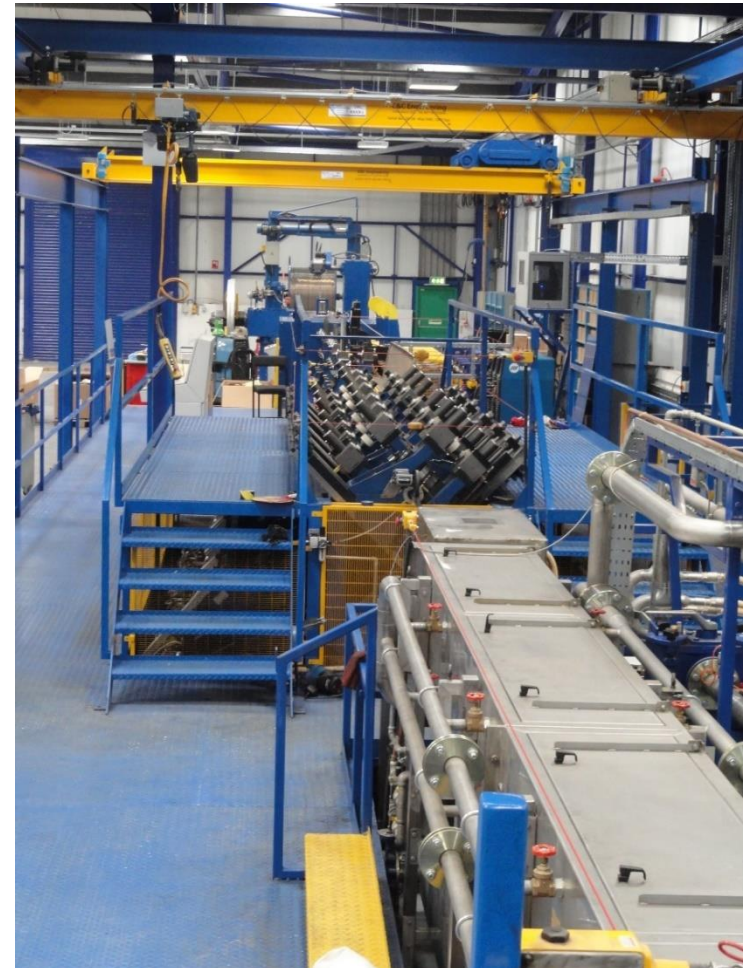
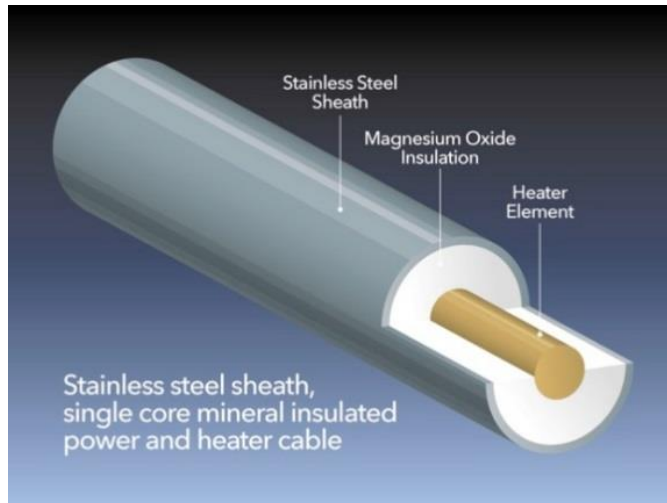


After extensive development, the Mineral Insulated (Electrical) heater is now commercially viable



## Salamander Heaters: Unmatched in Power, Length and Reliability

- Only cable that can deliver high power at long length without splices, leading to superior reliability
- An order of magnitude improvement over competing technology in the areas of heat and power delivery in harsh environments
- Unique, patent-protected manufacturing process
- Well-suited for subsea flowlines



# Technology in Action

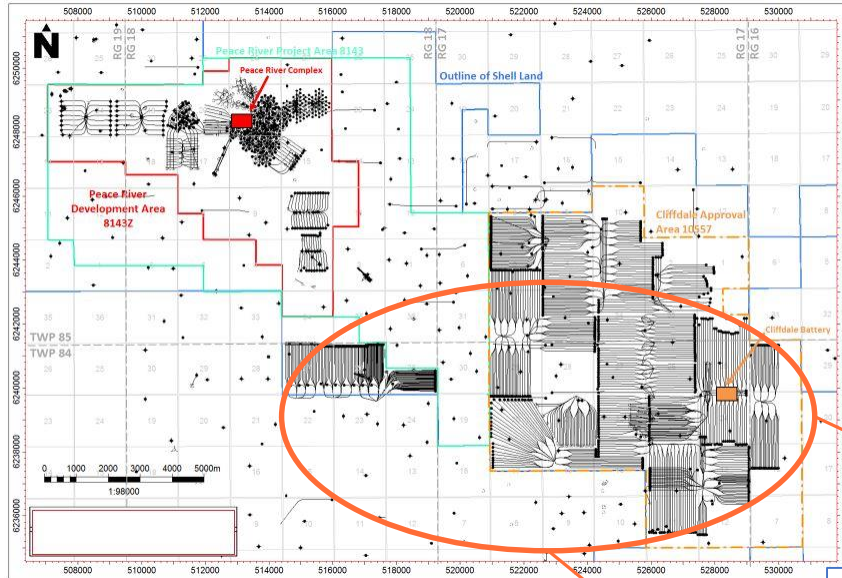
## Deployment in Alberta

## Canada – *In situ* Deployment of Heaters





## Asset Description

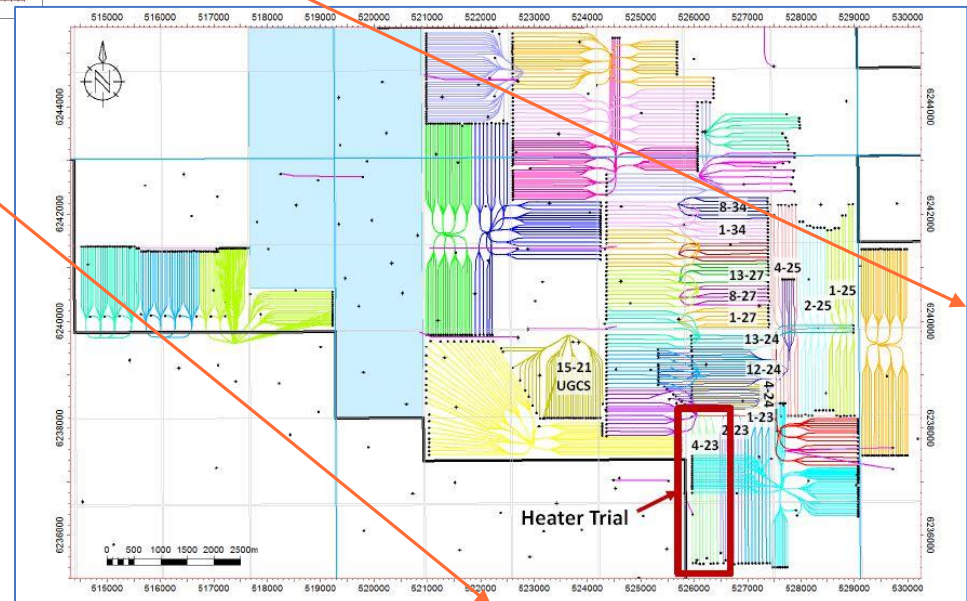


### Geology

- Pay: 20-40 m thick Bluesky formation
- Porosity: 0.24 – 0.26
- Permeability: 500 – 3,000 mD
- Viscosity: 5,000-20,000 cp (pay zone)
- Pockets of crestal gas may exist

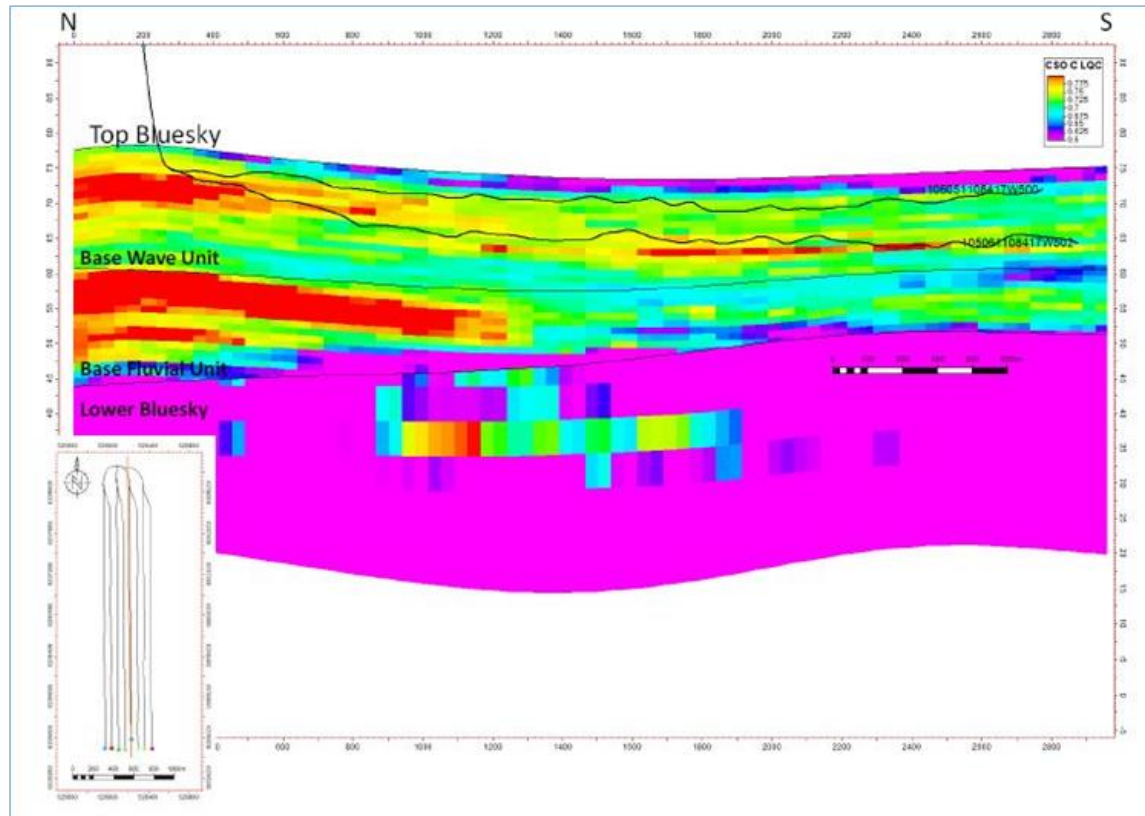
### Production

- Primary
- Horizontal Wells – single and dual laterals (occasional trilateral)
  - Lateral length: 1,200-2,500 m
  - Liner in only one of the two legs
- Progressing Cavity Pump



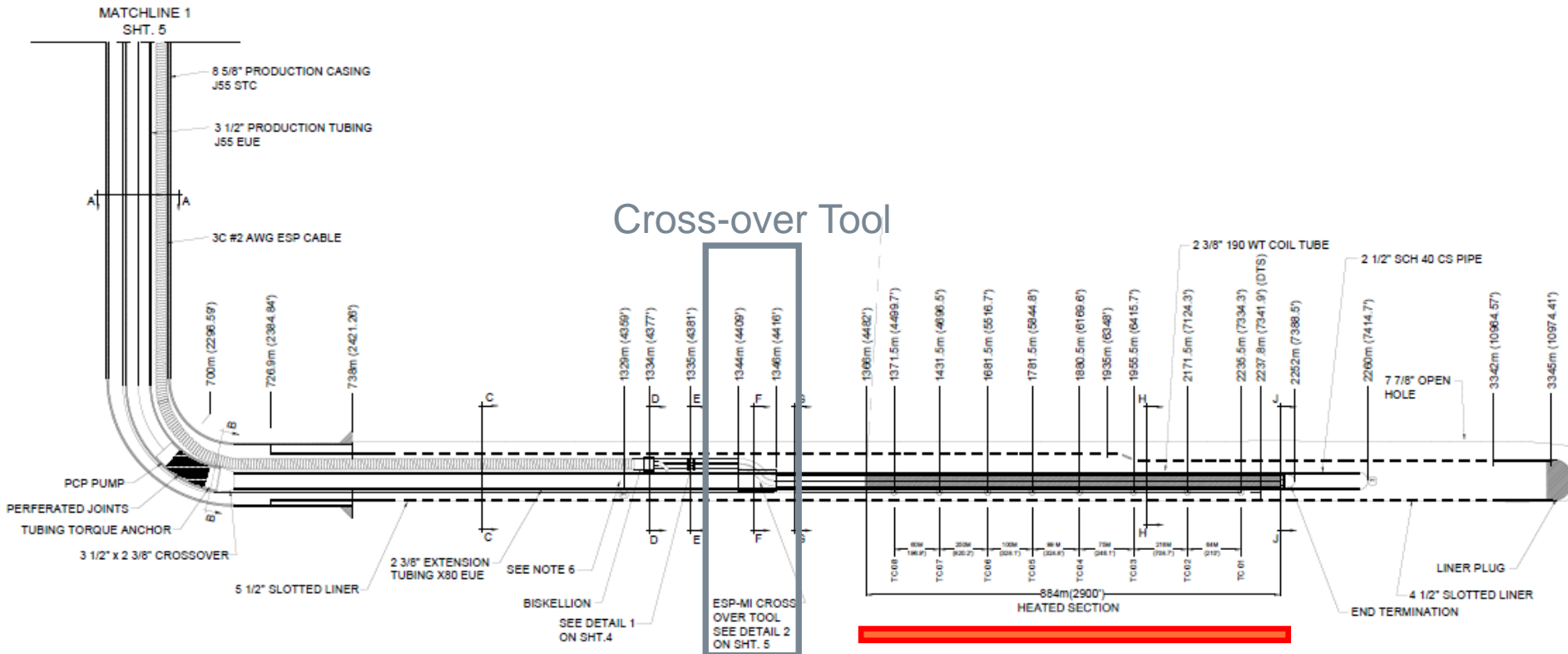
## Well Trajectory – Dual-lateral Production Well

Oil Saturation:  $0.72 < S_o < 0.80$



- Black curves show the trajectory of the laterals
- Heater is installed in the lower lateral

# Downhole Heater in Production Well, Alberta, Canada



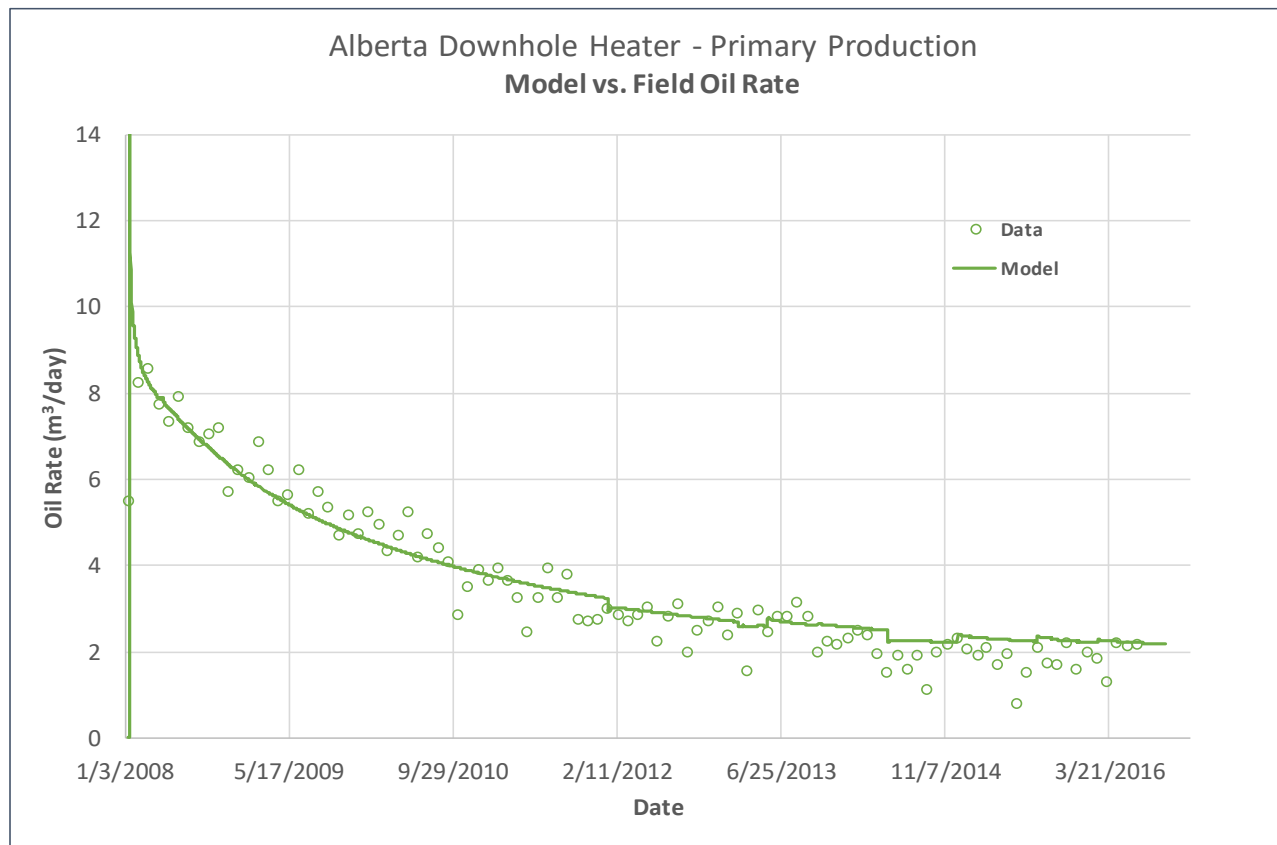
- 'Stinger' configuration: 884-m-long heater inside coiled tubing
- Novel cross-over piece tool lead cable from annulus to heater
- ESP cable clamped to tubing at every joint and mid-joint



## Downhole Heater – Deployment in Alberta, Canada

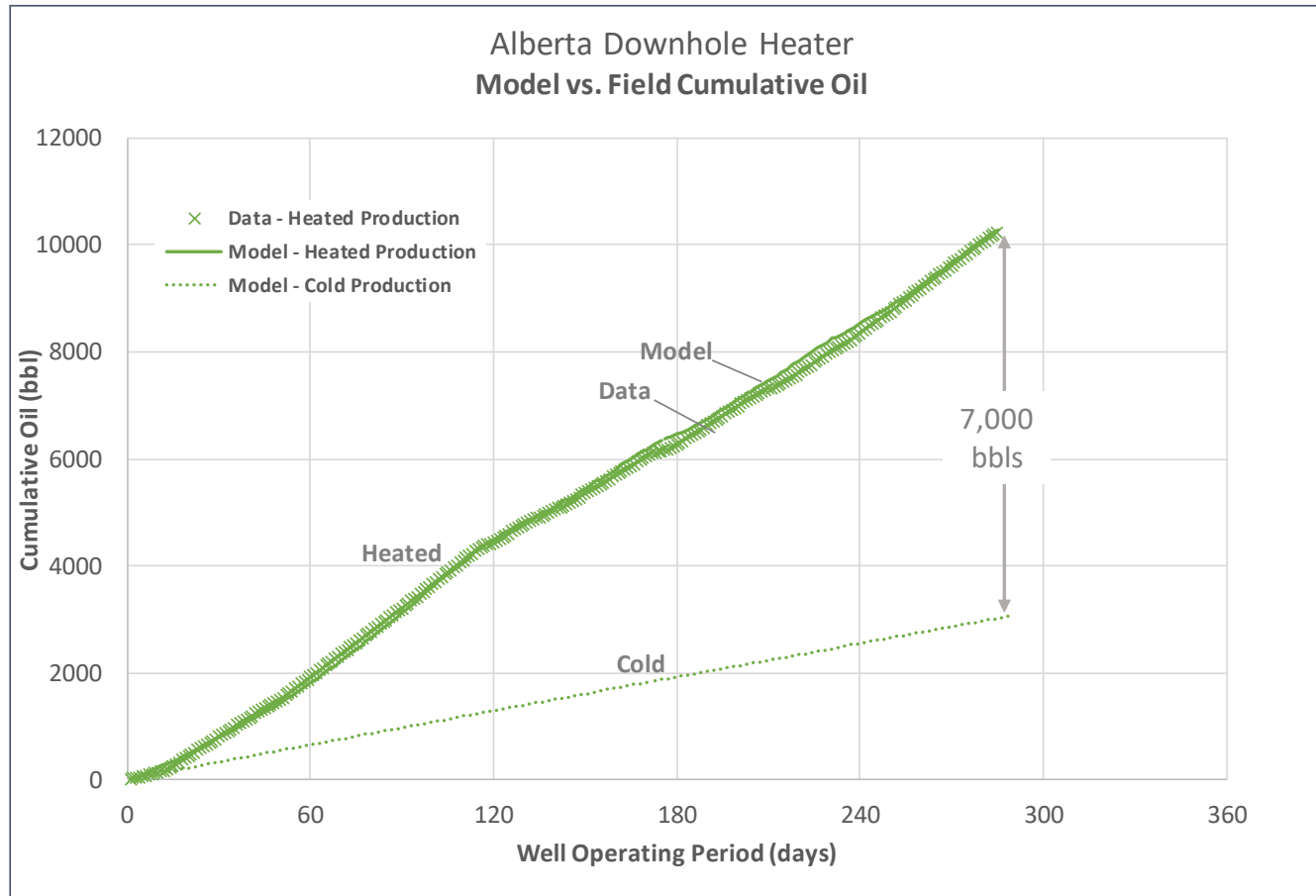


## Oil Production – Field Data and History-Match



- Well had been cold-producing for almost nine years
  - ✓ Ample data to understand/history-match well performance
  - ✗ Depleted reservoir energy

## Oil Production – Field Data and Model



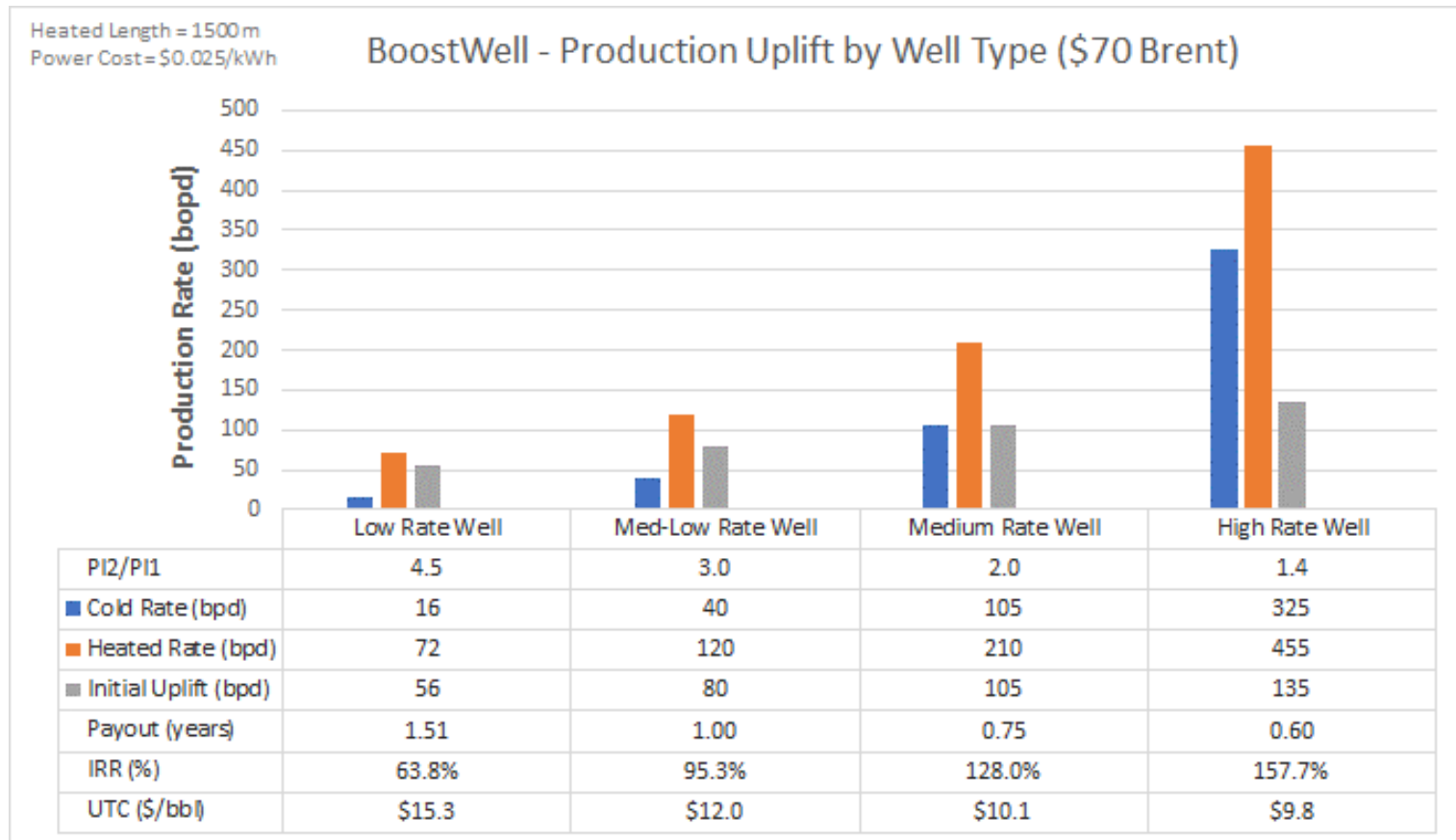
### Conclusions

- Heater performance is not affected by power fluctuations
- Heat in → Oil out, as forecasted by reservoir model (CMG-STARs)



# Downhole Heater Economics

## Downhole Heating Economics – Customer's View

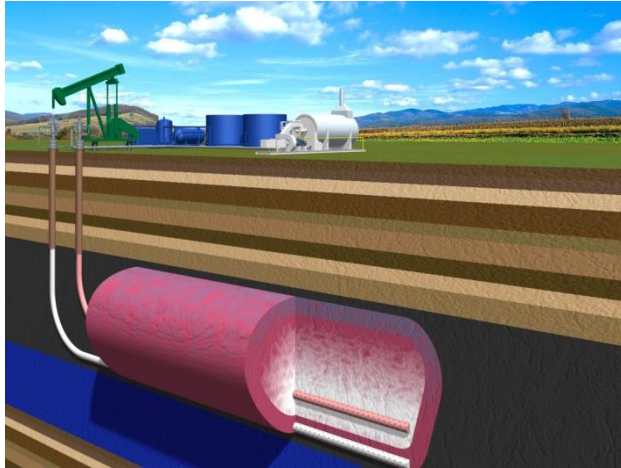


### Assumptions

- Significantly discounted market price of oil (Western Canada)
- Market value of produced gas is zero

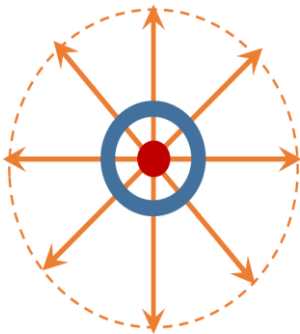
# Downhole Heater – Other Onshore Applications

## SAGD Downhole Pre-heating– LinkWell

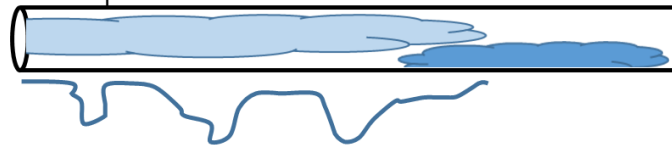


### SAGD Pre-heating Benefits

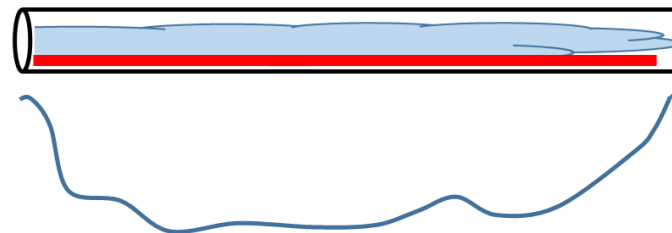
- Accelerating steam injection and thus first oil
  - e.g. SAGD pre-heat
- Improving steam injectivity and conformance
  - Balanced mobility contrast



Steam injection with no heater



Steam injection with heater



## Summary

- Salamander Solutions have brought into the market MI cables with an order-of-magnitude better reliability and length for heating of wells and flowlines
- A 2260-m-long heater assembly was successfully deployed and has been operating for over a year in a dual-lateral horizontal production well that had been cold-producing for nine years
- Heater has been performing well and production improvement has been within expected range
  - Oil rate increased by >4X; water cut was reduced
- Subsurface heat delivery systems can be used in other applications (e.g. SAGD pre-heating, wax removal, subsea lines)

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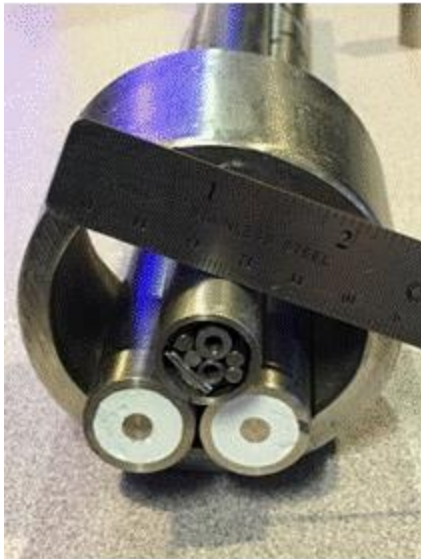
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## Salamander Solutions MI Heater in Coiled Tubing

- Salamander (ex-Shell) have installed ~25 heaters inside coil or strapped to tubing from 15 to 900 meters in US, Canada, and Jordan
- Salamander heaters have undergone extensive testing
- Heater operations have proven to be safe



## Downhole Heating – Advanced Reservoir Model

- Temperature versus distance from heated wellbore after ~6 months of heating

