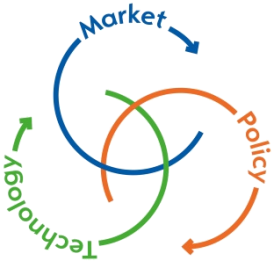


Isentropic®

Storage for End Use, Distribution and Island Systems

High Efficiency, low-cost thermal storage for Adiabatic CAES and Pumped Heat Electricity Storage

James Macnaghten, CEO, Isentropic Ltd

Energy Storage
Global Conference
Explaining I Exchanging I Enabling
Paris | 19th to 21st November 2014

About Isentropic Ltd

Isentropic®

Technology Development Company since 2005

- Urgent and growing requirement for low cost energy storage
- Only current cost effective solution is pumped-hydro
- Isentropic is developing unique thermo-mechanical solutions
- This approach is the only way to achieve low costs
- Pilot plant under construction

Isentropic Ltd works with the Energy Technologies Institute and Western Power Distribution on development of *Isentropic*® Pumped Heat Electricity Storage (PHES) as part of the Distribution-Scale Electricity Storage project.

WESTERN POWER DISTRIBUTION

Serving the Midlands, South West and Wales

World Class Partners

Isentropic®

In 2012 the ETI invested £14m in Isentropic

Energy Technologies Institute

energy technologies institute

ETI members

bp

CATERPILLAR®

EDF ENERGY

e·on

Rolls-Royce

Department of Energy & Climate Change

Department for Business Innovation & Skills

EPSRC Pioneering research and skills

Innovate UK Technology Strategy Board

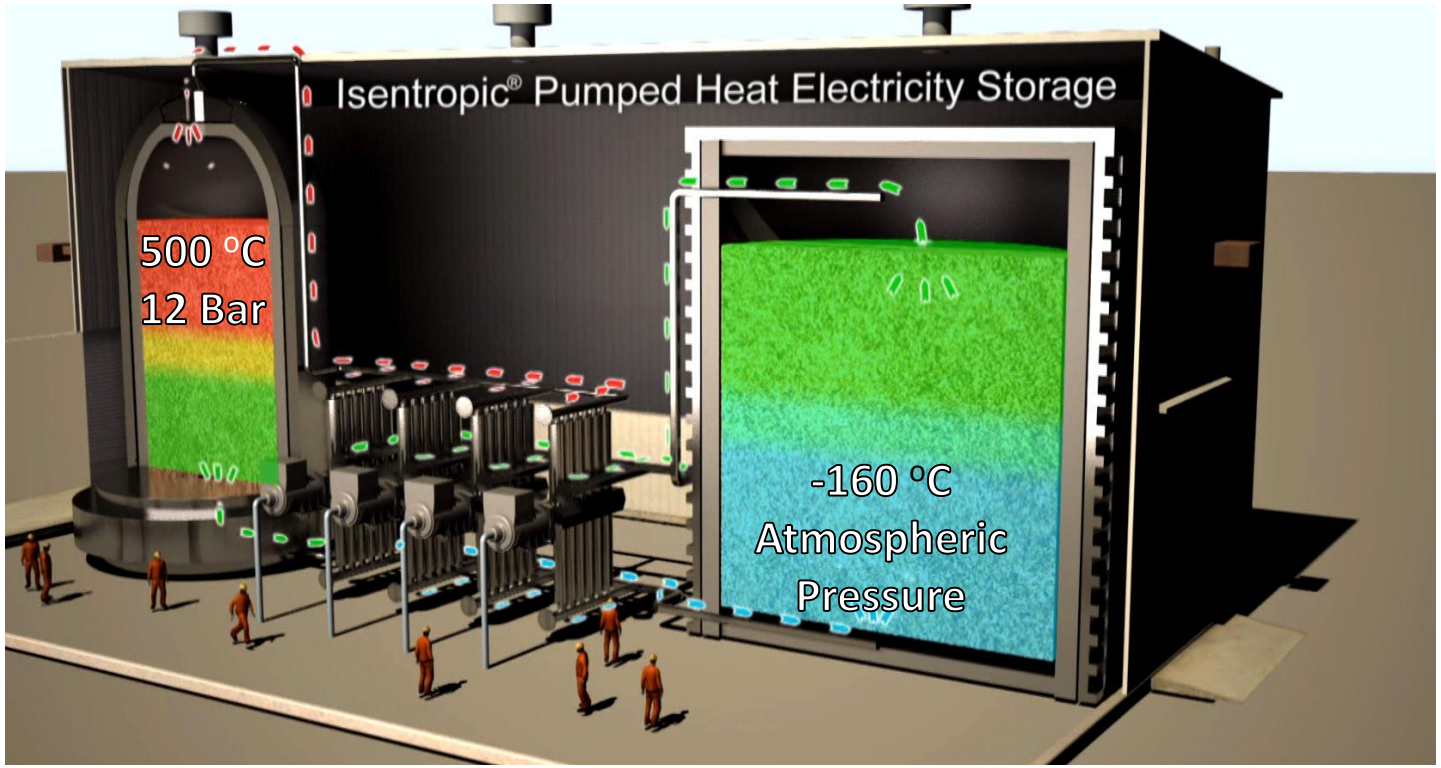
ETI programme associate

HITACHI Inspire the Next

Pumped Heat Electricity Storage

Isentropic®

Hot and cold thermal stores



About Isentropic Ltd

Isentropic®

Pumped Heat Electricity Storage

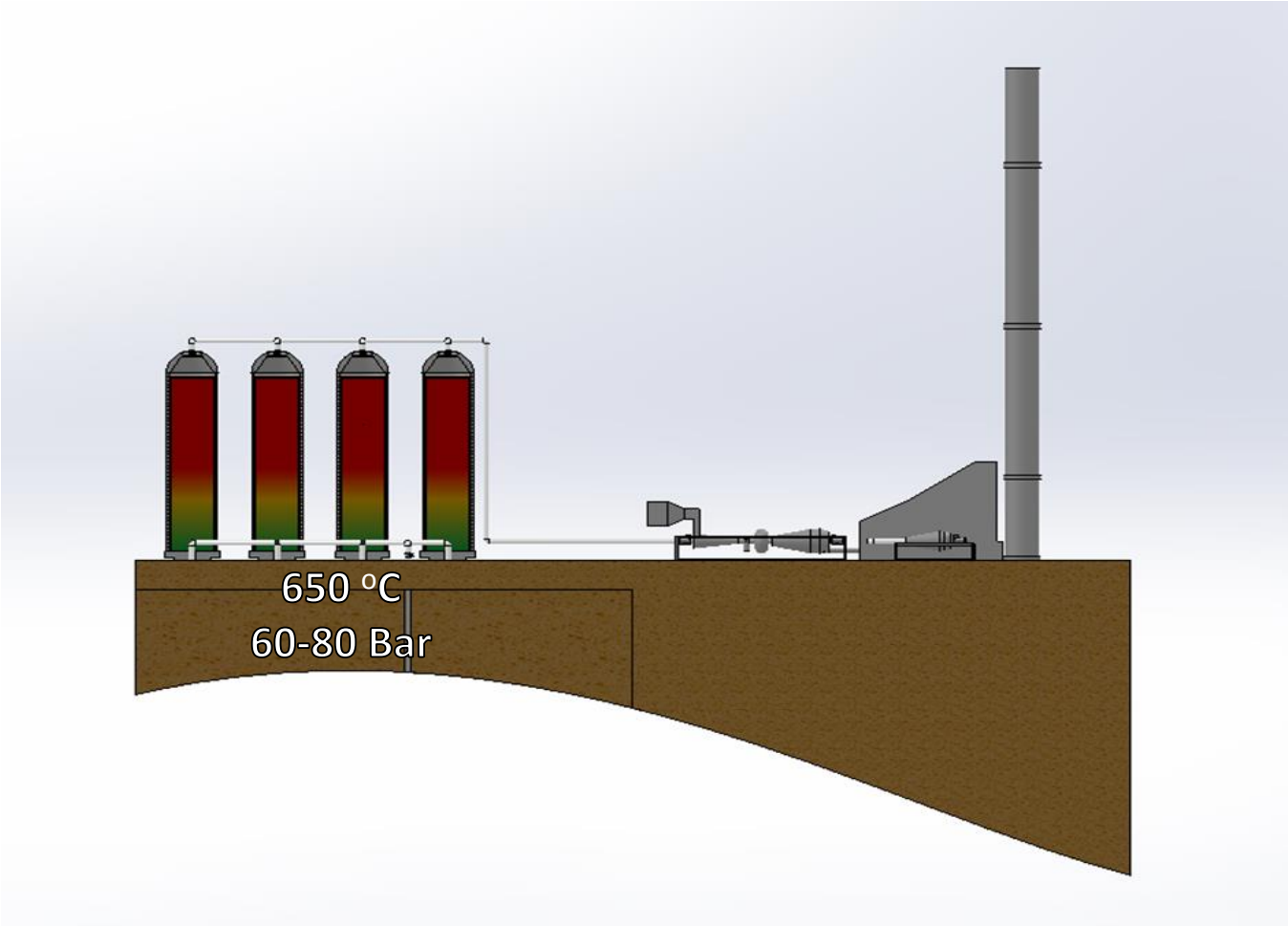
Key Features:

- Low Capex ~ $200/kWh fully installed
- Long cycle life >100,000 cycles
- Rapid Response
- High roundtrip efficiency – 75%
- Site Anywhere
- Long physical life (25 years)
- Safe and Clean – No end of life issues

Adiabatic CAES

Isentropic®

Hot high pressure thermal stores for CAES



Thermal Storage

Isentropic®

Isentropic requirements for thermal storage

- Operating temperature range −160 °C to 600 °C
- Constant temperature during discharge
- Very high efficiency >95%
- Safe
- Scaleable
- Low Cost ???

Thermal Storage

Isentropic®

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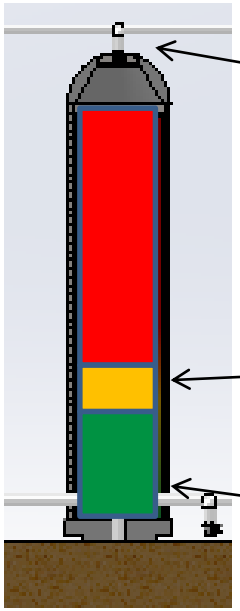
A packed bed thermal store can achieve all of the above

Packed Bed Thermal Stores

Isentropic®

How a packed bed works



Hot gas or air enters at 500 °C

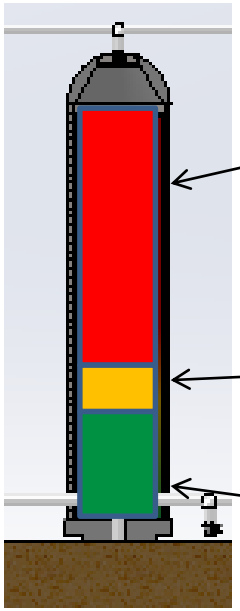
Thermal media (normally crushed rock) is heated up by direct heat exchange with the gas

Cold gas or air exits at 40 °C

Packed Bed Thermal Stores

Isentropic®

Temperature profile in a packed bed



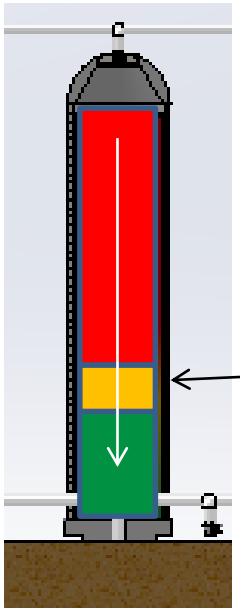
Thermal media all at hot temperature 500 °C
Minimal heat exchange

Temperature varies from 500 °C to 40 °C
Majority of heat exchange
Region with a 'thermal front' or thermocline

Thermal media all at cold temperature 40 °C
Minimal heat exchange

Packed Bed Thermal Stores

Movement of thermal front during charging

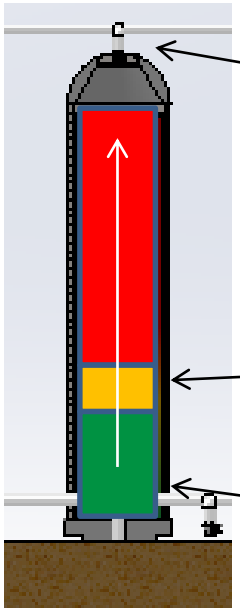


As the thermal store is charged the thermal front moves from near the top of the store to the bottom of the store

Packed Bed Thermal Stores

Isentropic®

Discharging



Hot gas or air leaves at close to 500 °C

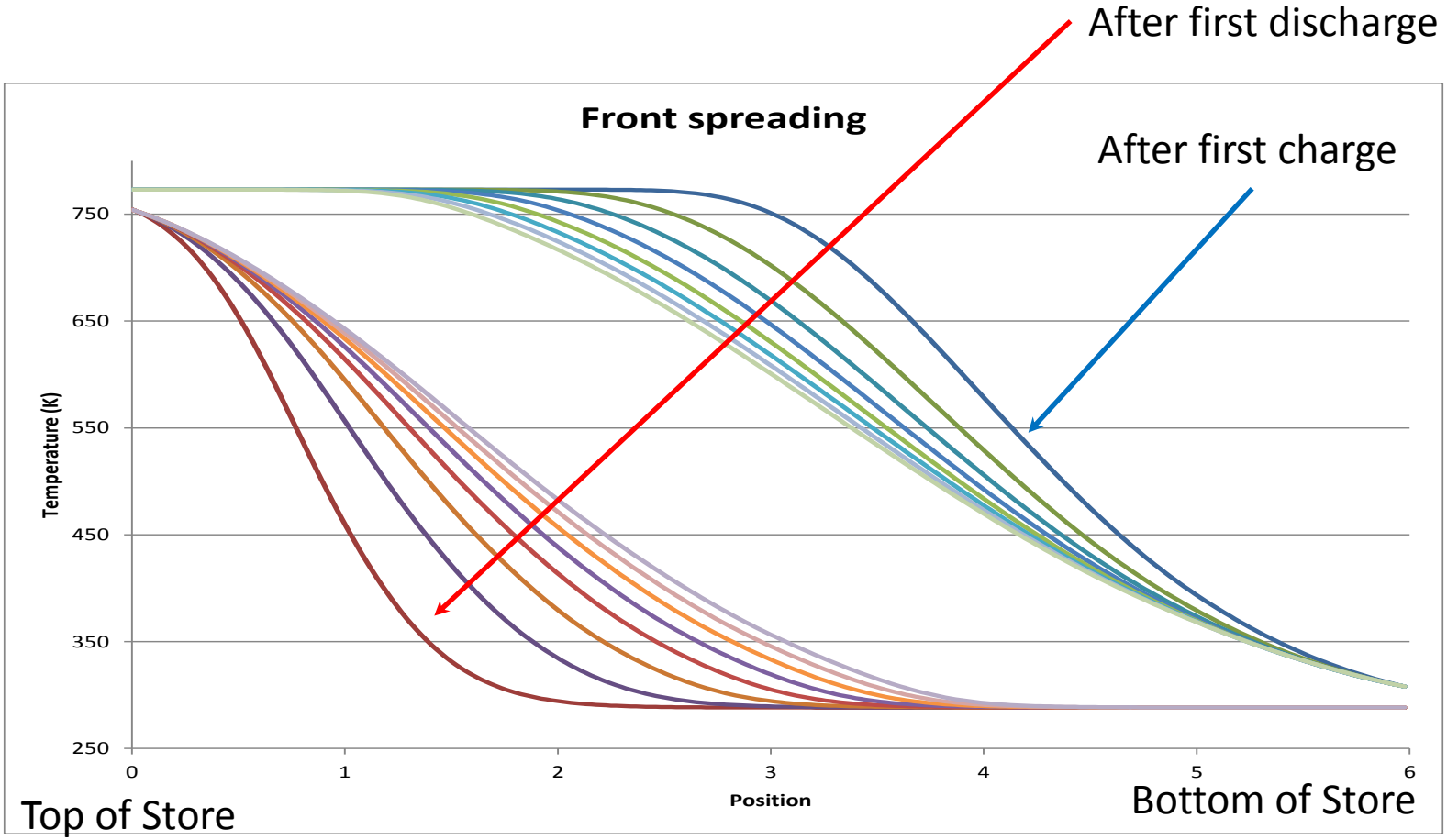
Thermal front moves up the store as the media is cooled down by direct heat exchange with the gas

Cold gas or air enters at less than 40 °C

Normal Packed Bed

Isentropic®

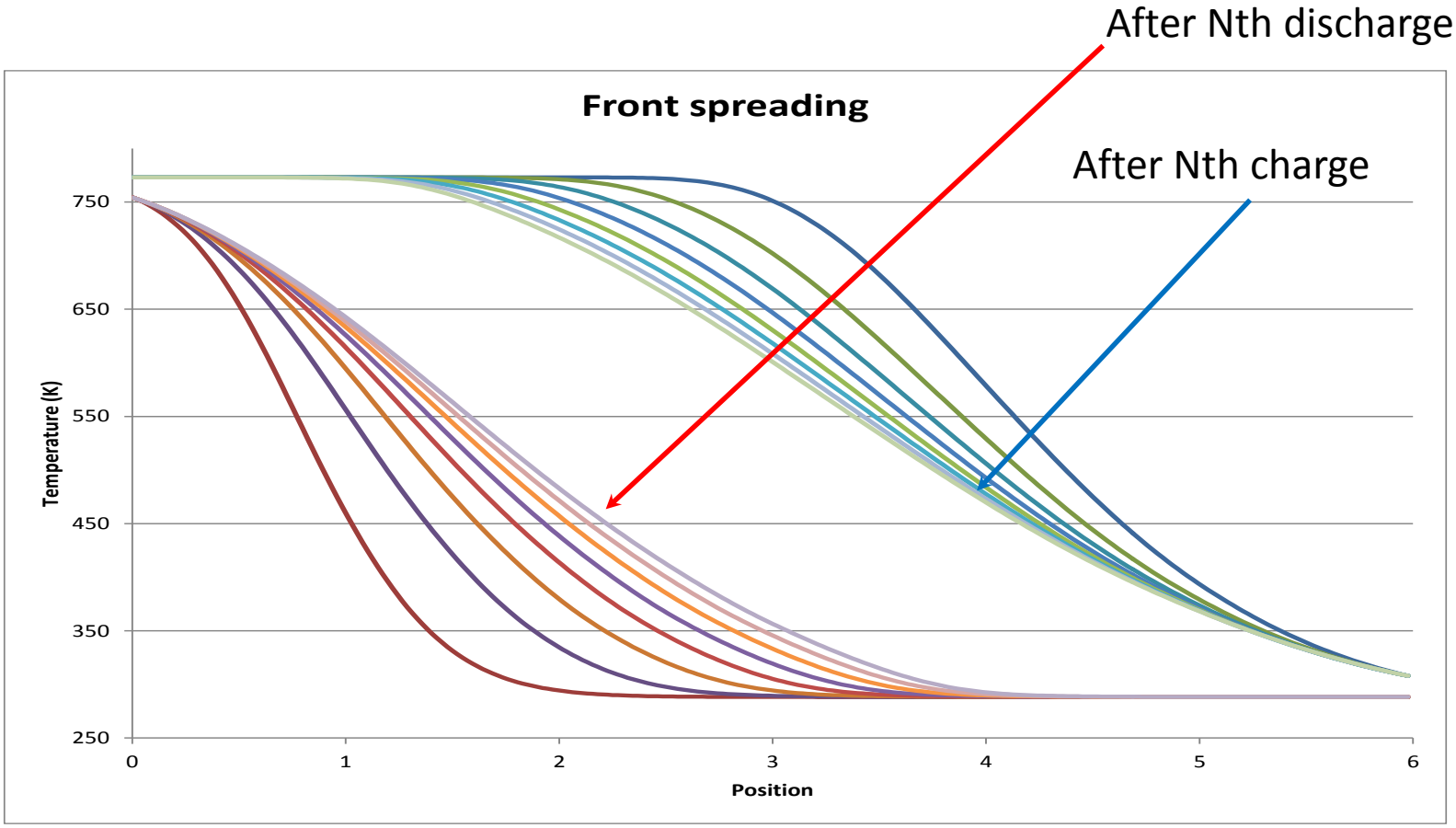
Typical temperature profile in a packed bed store



Normal Packed Bed

Isentropic®

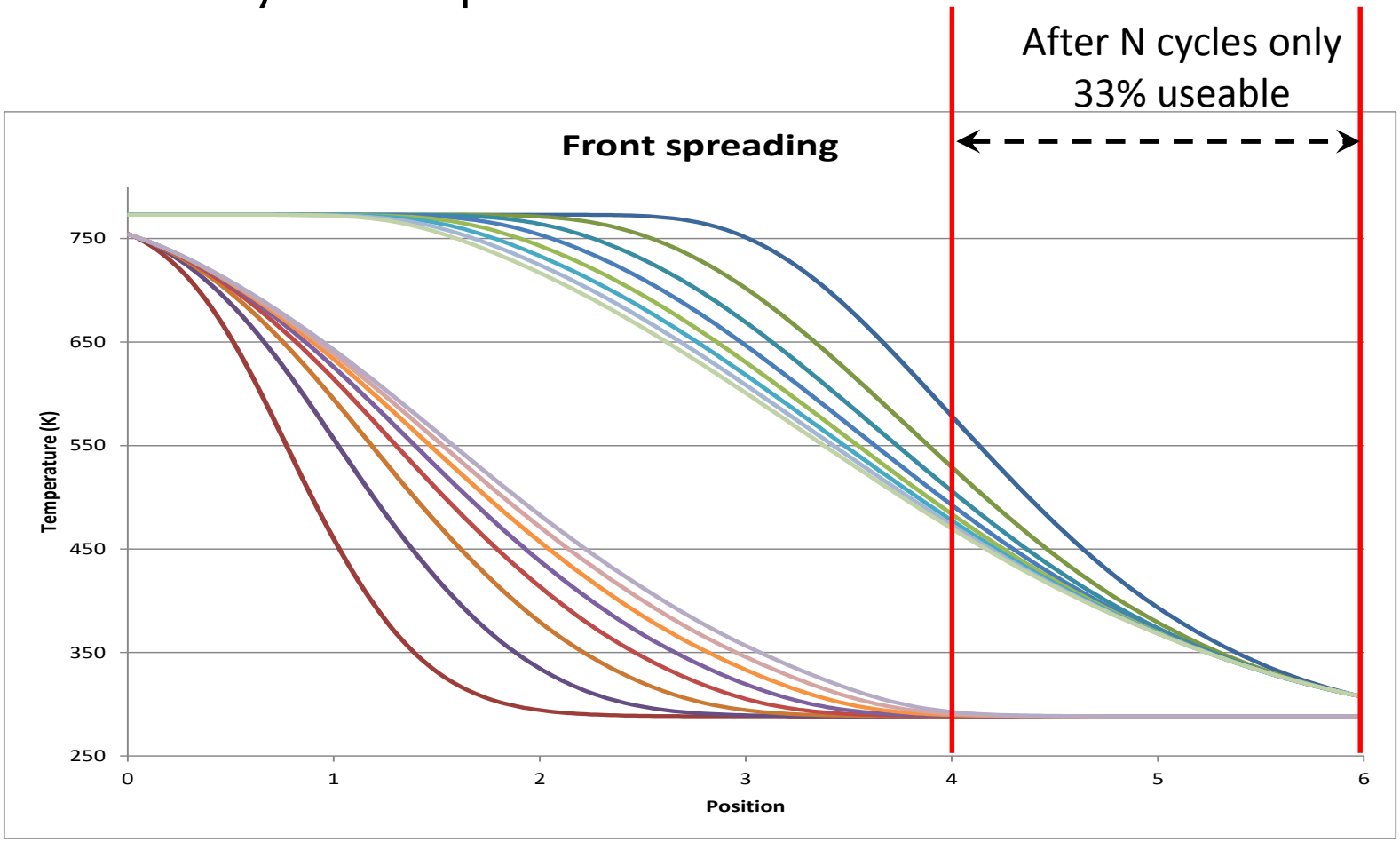
Steady State Operation



Normal Packed Bed

Isentropic®

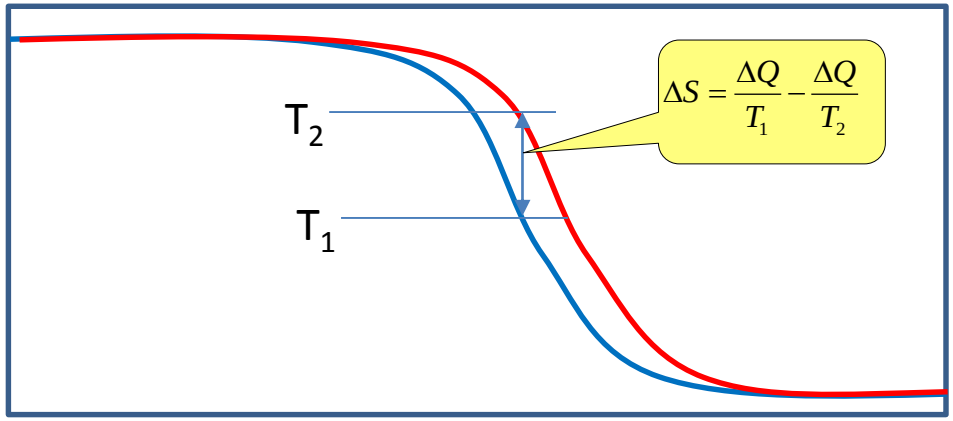
Steady State Operation



Efficiency

Isentropic®

Major loss mechanisms in thermal stores



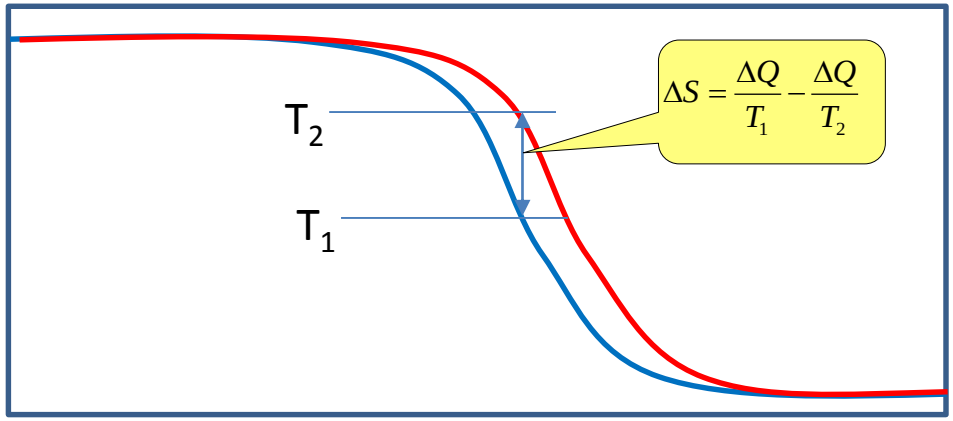
$$\Delta S = mR \ln\left(\frac{p_1}{p_2}\right)$$

	Small particles	Large particles
• Heat Transfer	Good	Poor
• Pressure Drop	Poor	Good
• Exit Loss		

Efficiency

Isentropic®

Major loss mechanisms in thermal stores



$$\Delta S = mR \ln\left(\frac{p_1}{p_2}\right)$$

- Isentropic Ltd has invented a system which allows the use of small particles with a low pressure drop and low exit loss.

Layered Thermal Stores

Isentropic® thermal stores are split into multiple layers.

Gas flow is diverted so that it only passes through areas with active heat exchange

Layered Thermal Stores

Isentropic®

Start of Charge

Layered Thermal Stores

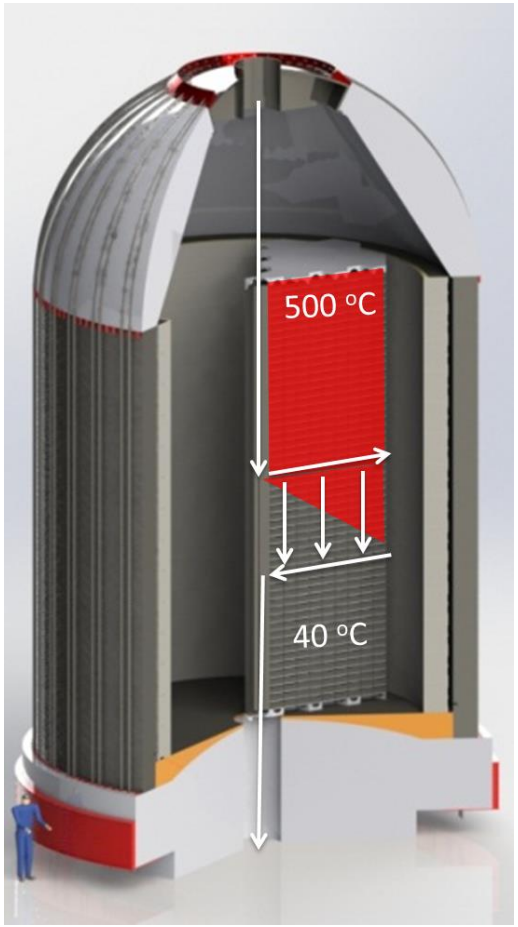
Isentropic®

Charging

Layered Thermal Stores

Isentropic®

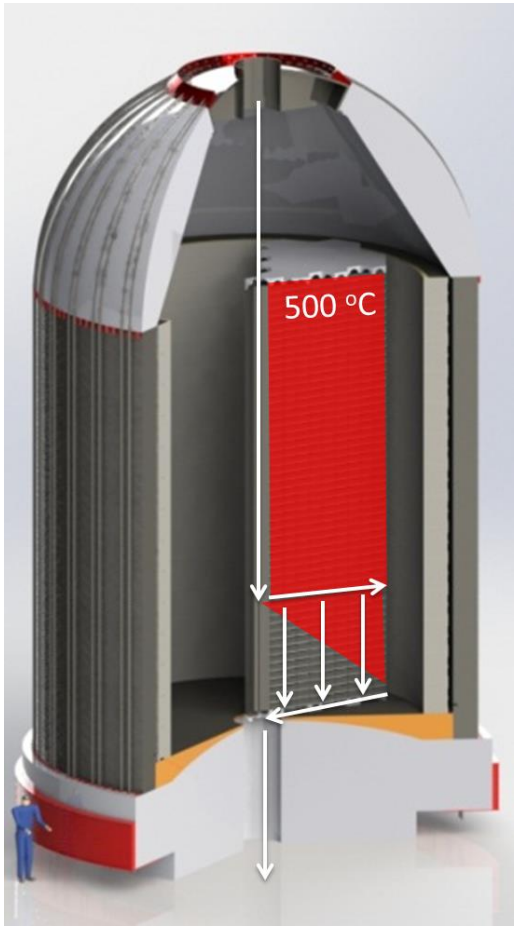
Charging



Layered Thermal Stores

Isentropic®

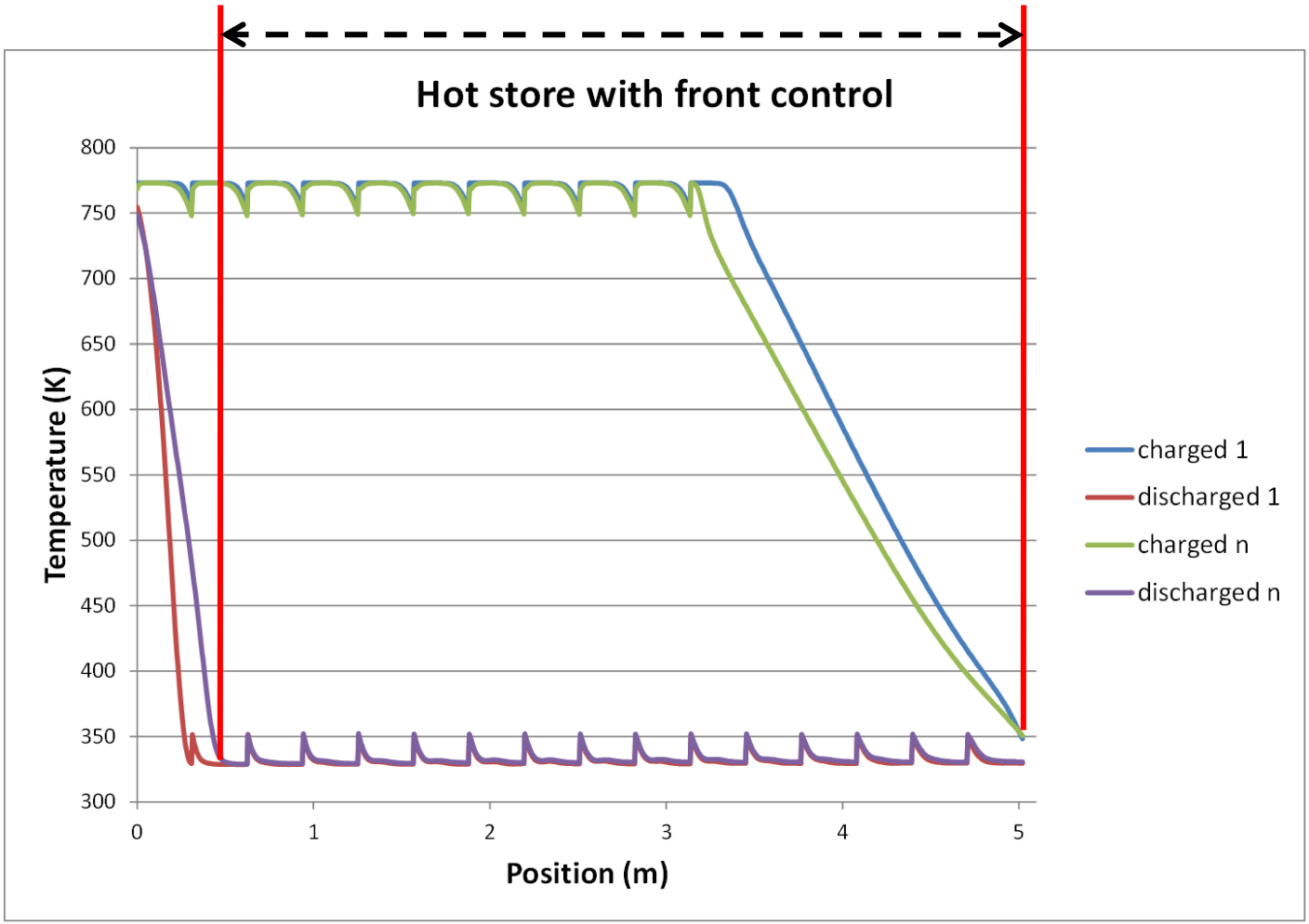
Fully Charged



Layered Thermal Stores

Isentropic®

After N cycles >90% can be used



Benefits of Layering

Isentropic®

- Increase energy density by a factor of 2-3 x
- Reduces pressure vessel cost by a factor of 2-3 x
- Allow precise management of part-charge / part-discharge cycles.
- Allows near constant discharge temperatures

Layered Stores are NOT just theory

Isentropic®

Validated internally by analysis, supported by physical testing

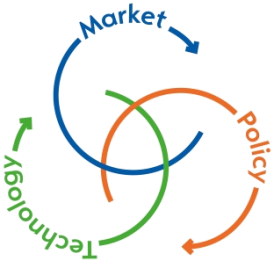
Validated externally by independent expert

Layered Thermal Stores

Isentropic®

Summary

- *Isentropic*® thermal stores are split into multiple layers
- High Efficiency 96% – 99%
- Compact with 2-3x energy density compared to an unlayered store – Low Cost
- Safe
- Can be scaled from small to large size (10,000 tons)
- Temperature range -160°C to 600 °C



Isentropic®

Thank you for your attention

James Macnaghten
CEO
Isentropic Ltd