Mitigation of Greenhouse Gas Leakage from Oil and Gas Wells

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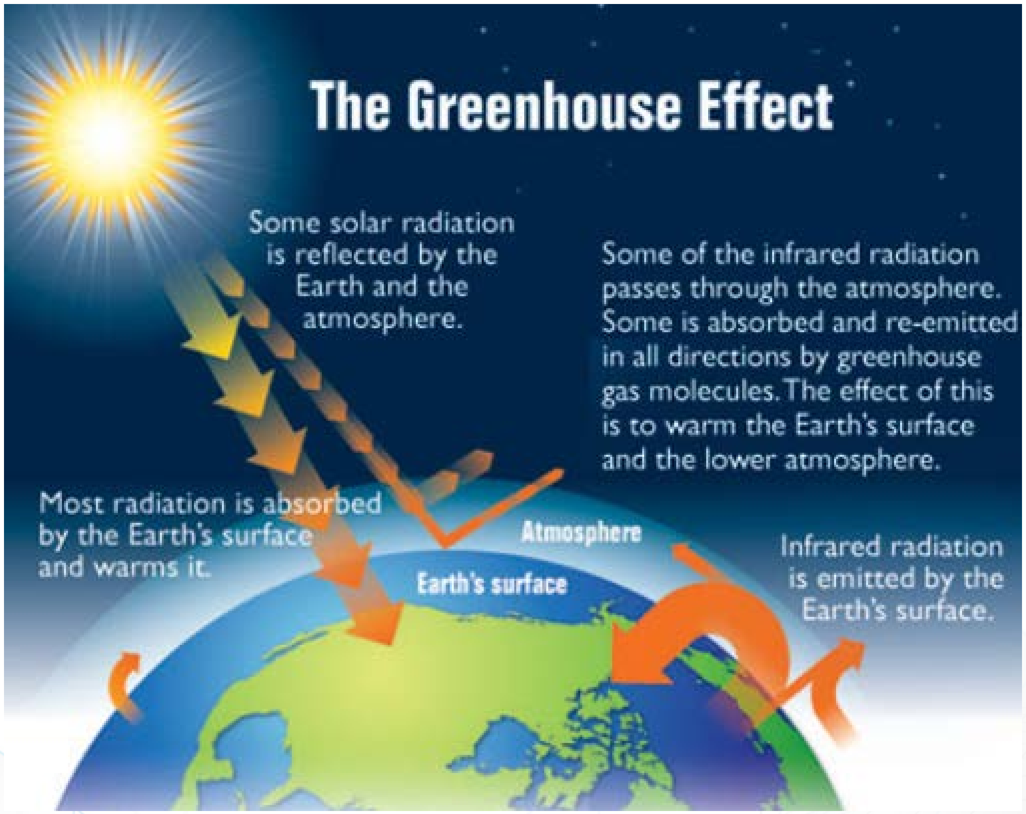
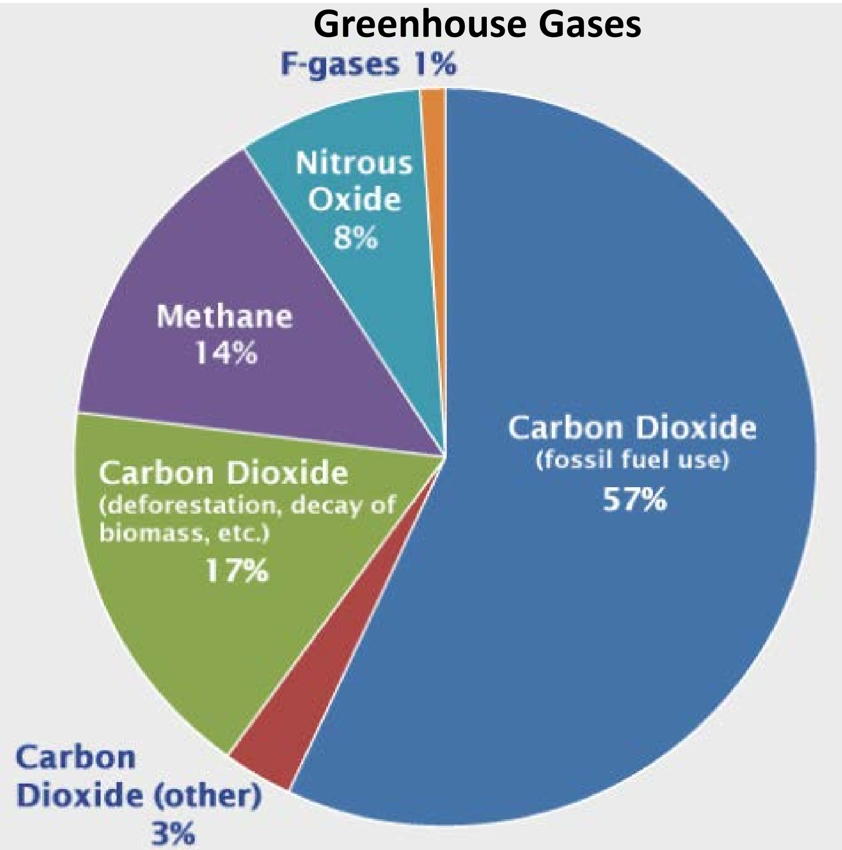
Background

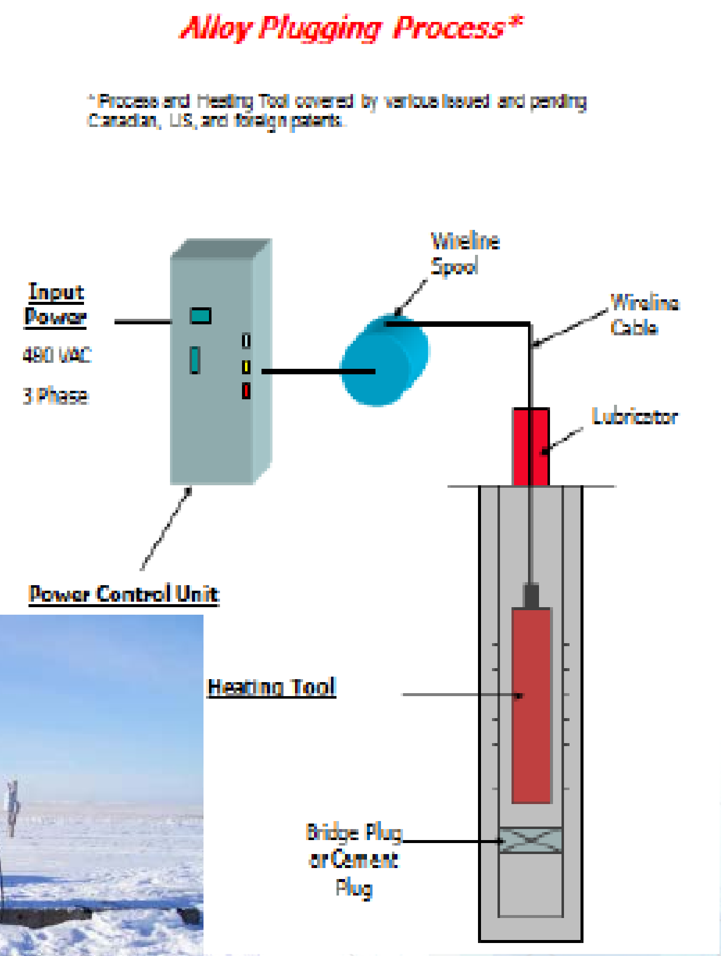


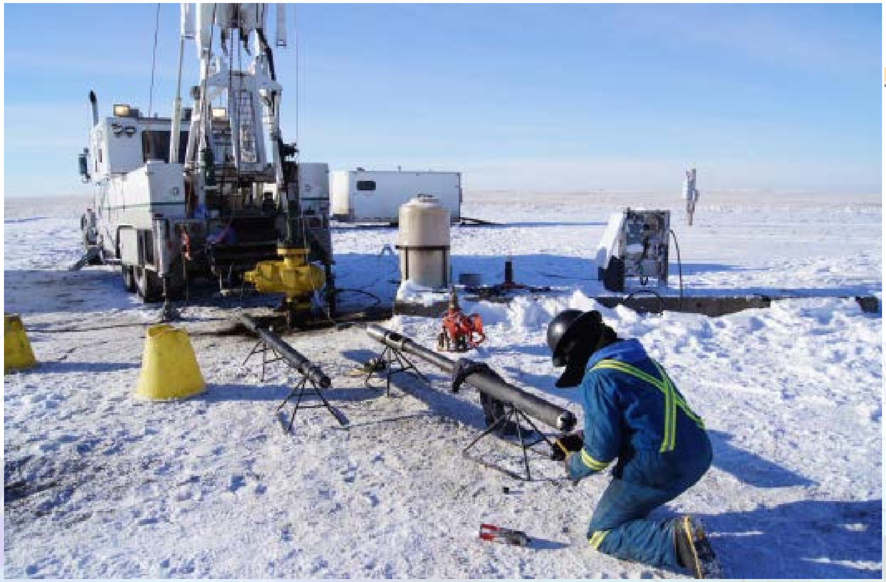


Leakage from sealed oil and gas wells in Alberta, Canada:
~3.5 million tonnes GHG per year
14% of sealed wells leak

Seal Well Technology

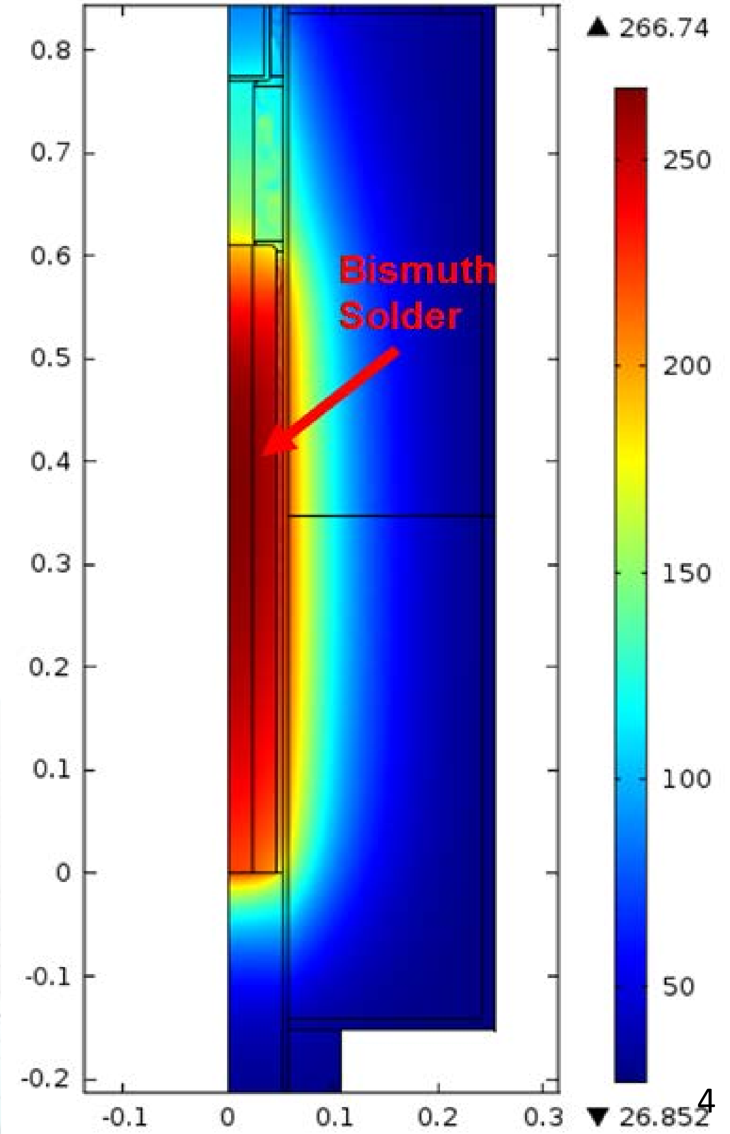
- Low melting point bismuth-tin alloy
- Molded *in situ* to produce a permanent seal





COMSOL Model

- **Heating to melt the bismuth-tin alloy in sufficient volume to infiltrate the porous structure around the well head**
- **Development of a stress distribution with sufficient strength to provide a permanent seal.**



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REALIZING TOMORROW'S TECHNOLOGY

COMSOL Model

- **Heat Transfer**
  - Conduction
  - Phase change

$$\rho \, c_p \frac{\partial T}{\partial t} = \nabla \cdot \left(\lambda \nabla T \right)$$

- **Fluid flow**
  - Conjugate heat transfer
  - Convection

$$\nabla \cdot \left(\rho \, \mathbf{u} \right) = 0$$

$$\rho \, \mathbf{u} \cdot \nabla \mathbf{u} = -\nabla p + \nabla \cdot \left(\eta \left(\nabla \mathbf{u} + \left(\nabla \mathbf{u} \right)^T \right) - \frac{2}{3} \eta \left(\nabla \cdot \mathbf{u} \right) \mathbf{I} \right) + \rho \, \mathbf{g}$$

$$\nabla \cdot \left(-k \nabla T \right) = Q - \rho \, c_p \mathbf{u}$$

- **Structural mechanics**
  - Isotropic hardening plasticity

$$\nabla \bullet \boldsymbol{\sigma} = 0$$

$$\boldsymbol{\sigma} = \mathbf{C} : \boldsymbol{\varepsilon}_{el}$$

$$\boldsymbol{\varepsilon}^T = \boldsymbol{\varepsilon}_{el} + \boldsymbol{\varepsilon}_{th}$$

$$\boldsymbol{\varepsilon}_{th} = \alpha_{th} \left(T - T_{ref} \right)$$

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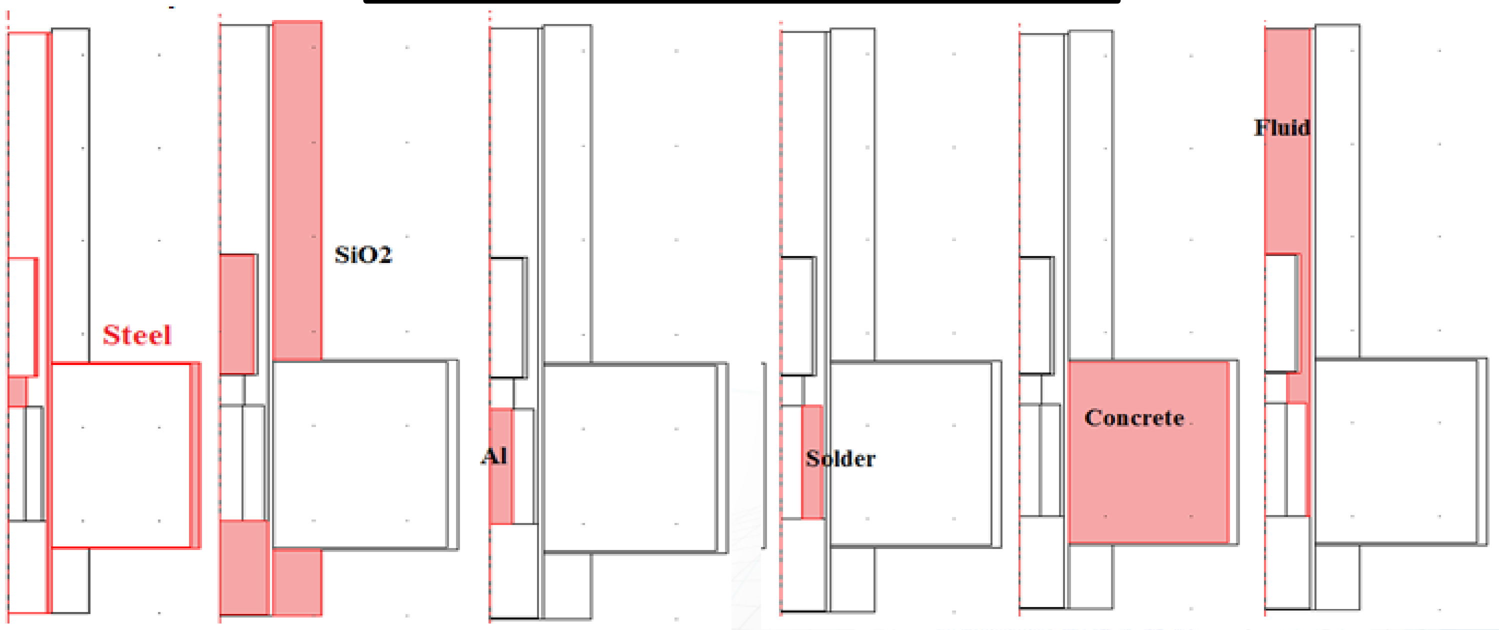
COMSOL Model - Heating

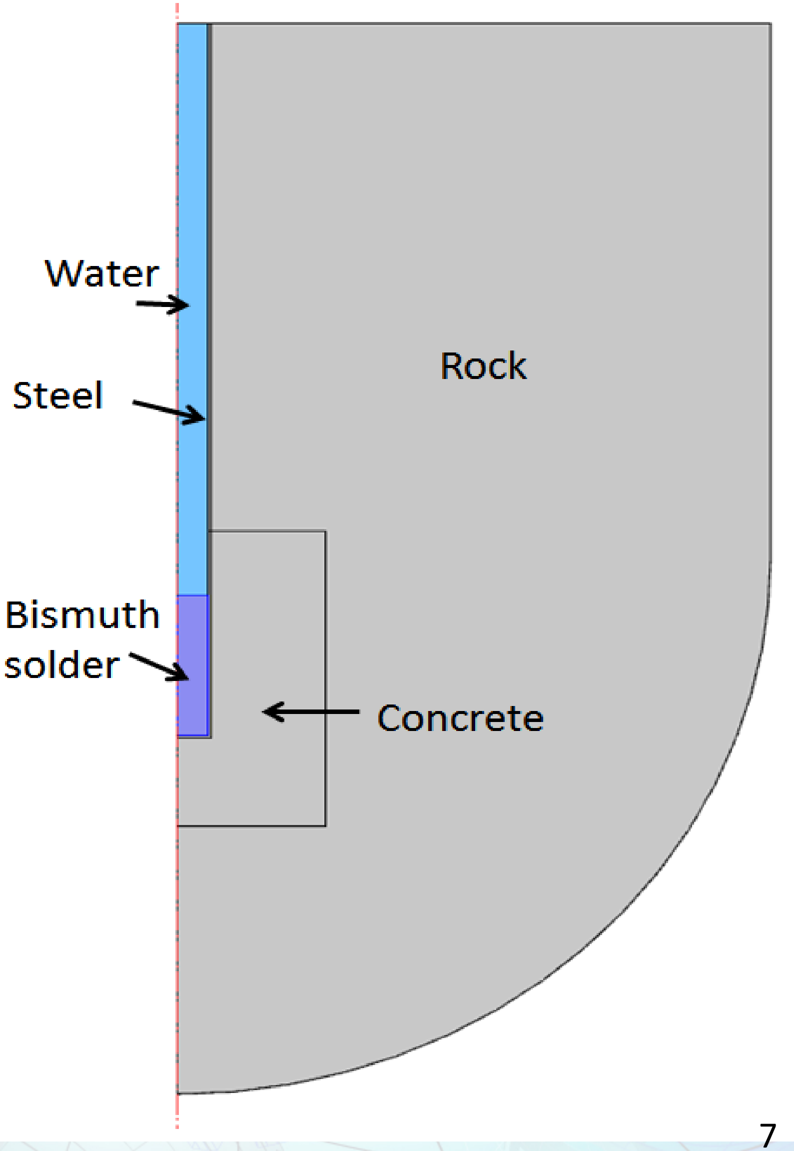
Axisymmetric model
Multiple material domains
Heater unit in place



Heat transfer
Fluid mechanics

COMSOL Model - Cooling

- **Axisymmetric model showing material domain**
- **Heater unit removed**
- **Liquid bismuth-tin solder pools at the bottom of the well**
  - **Heat transfer**
  - **Structural mechanics**



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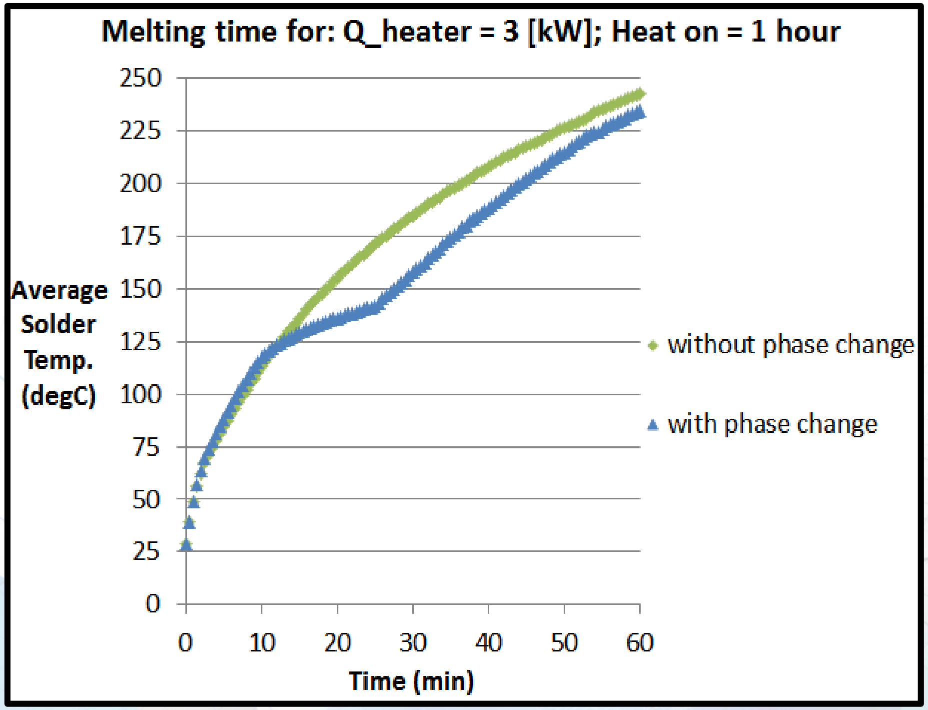
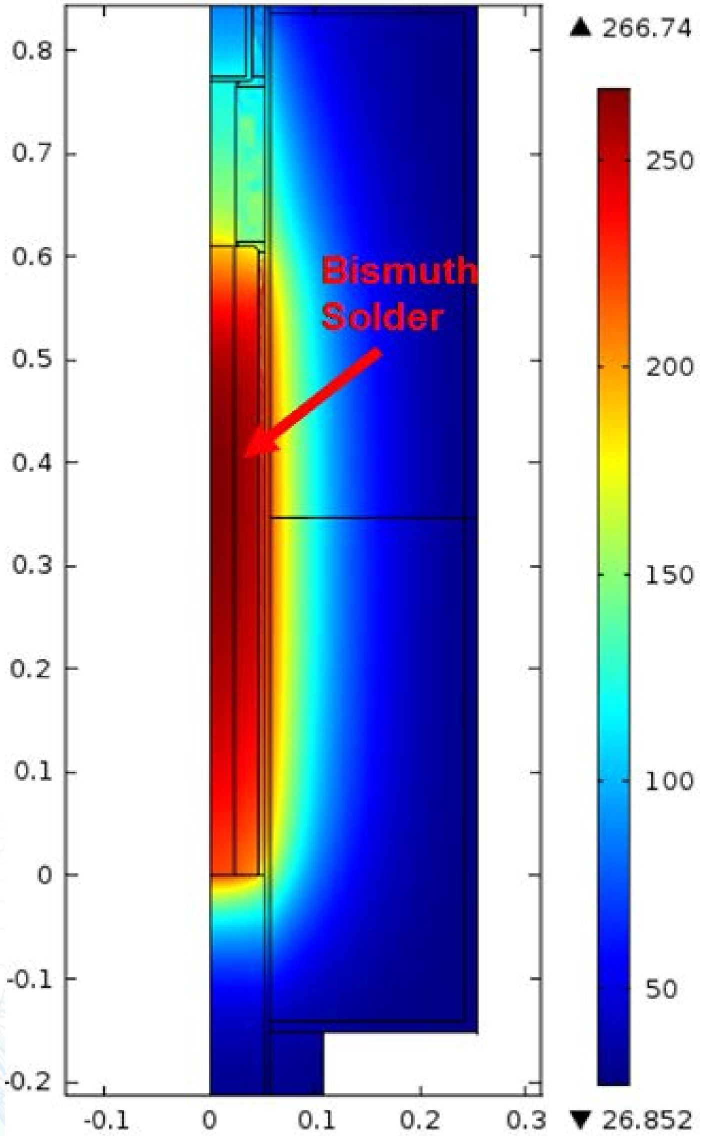
Results: Heating

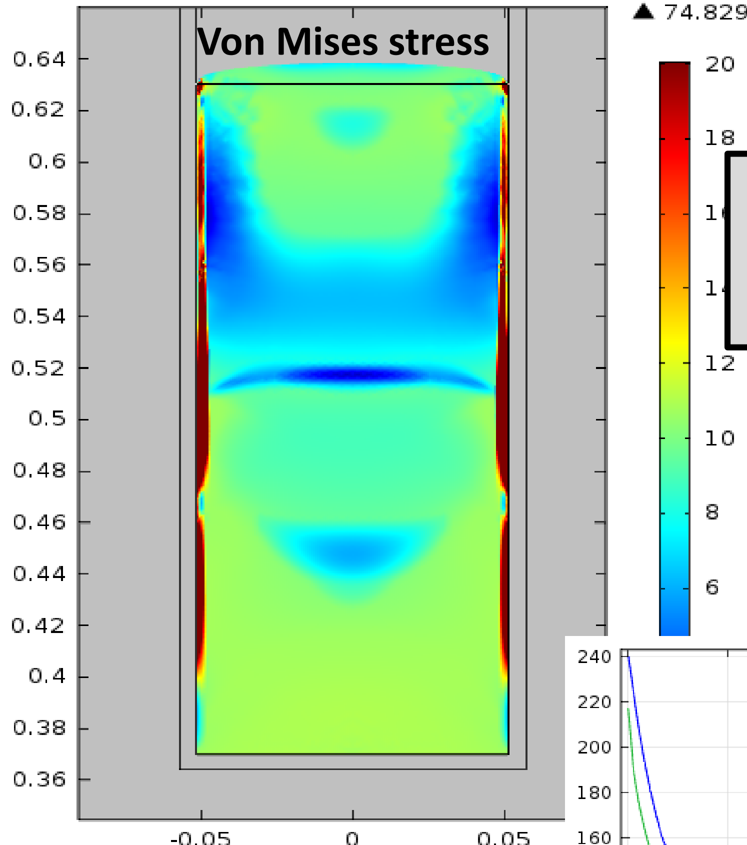
- Temperature vs time
- Temperature distribution
- Process conditions



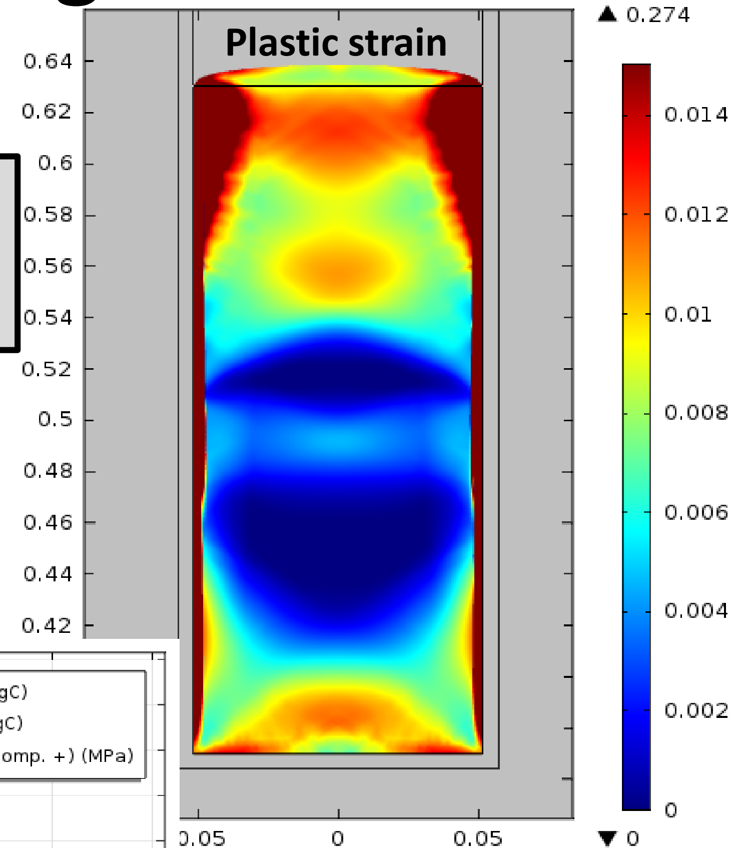


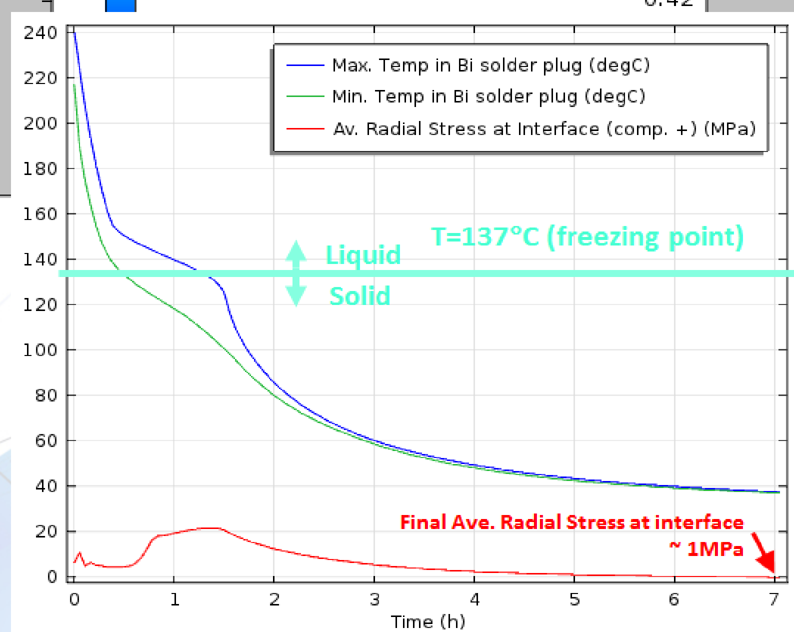
t = 3600s

Results: Cooling



Residual stress/strain distribution in well seal region





Summary

- **Computational model of Seal Well's technology for sealing GHG emitting wells has been used for:**
  - **Development of effective processing parameters**
  - **Identification of solidification induced residual stresses**
- **Seal Well technology currently under demonstration and implementation**

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	Model with heater unit	*Model with heater unit removed*
• **Boundary conditions:**	**Conjugate heat transfer: No slip velocity at all walls, pressure point constraint at about 2.5 meters in the vertical direction from the bottom of the water column, Fixed rock temperature at a circular radius of 4 meters away from unit in rock formation.**	***See following slides***
• **Typical Model size:**	**100k DoF**	**Heat Transfer step: 4k DoF** **Solid Mechanics step: 26k DoF**
• **Typical Run times:**	**17 hours of walltime for 1 hour of simulation time to completely melt the alloy**	**Heat Transfer step: 0.5 hours** **Solid Mechanics step: 5 hours**

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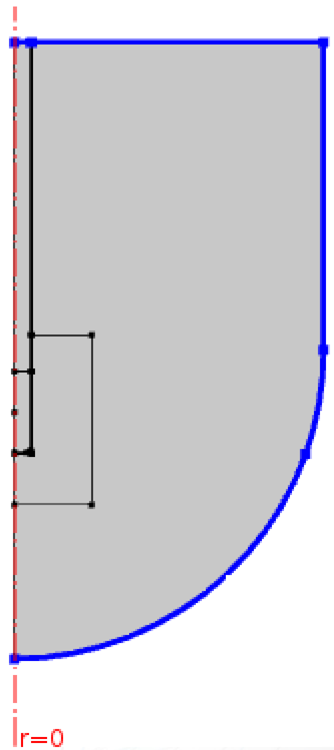
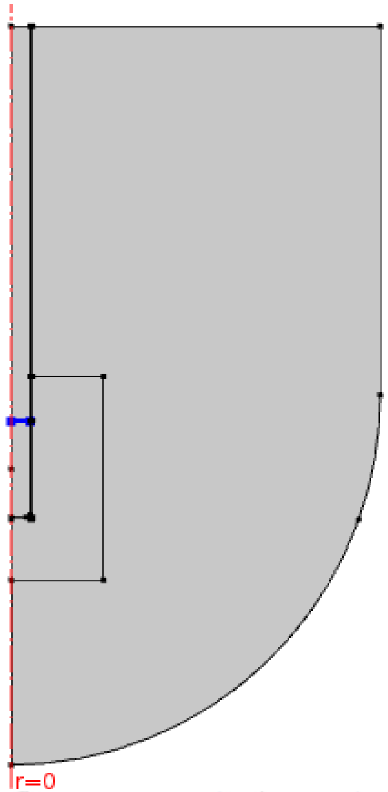
Model with heater removed (Heat Transfer boundary conditions)

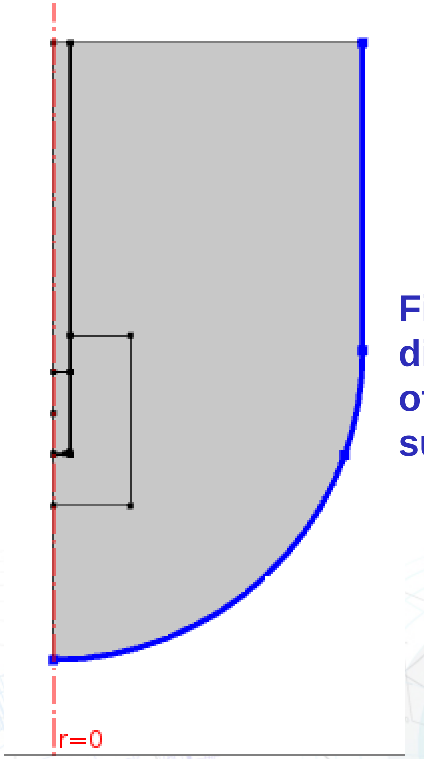


Fixed temperature to rock temperature on blue surfaces

Model with heater removed (Solid mechanics boundary conditions)

Boundary load (pressure of water column) on blue surface





Fixed displacement of u = 0 on blue surfaces