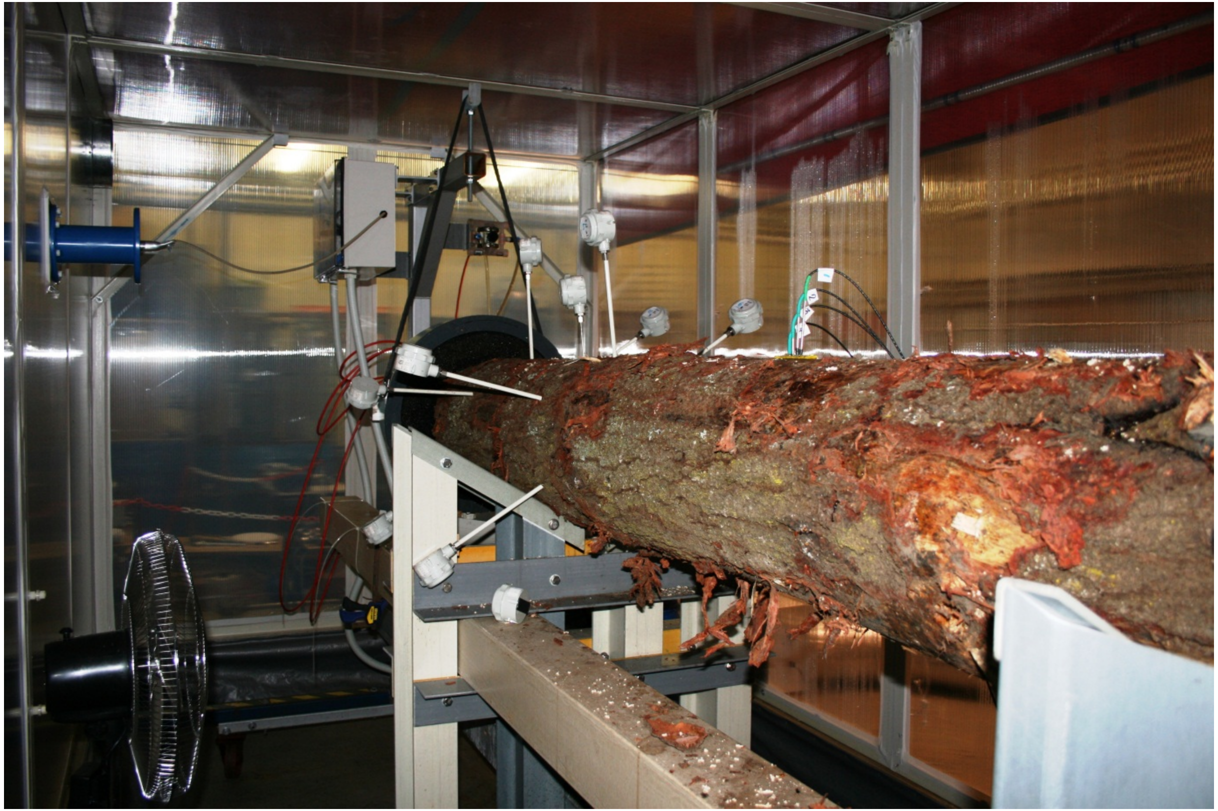
Joule Heating as a Multipurpose Heat Treatment



A Potential Alternative to Fumigation & Hot Water/Steam Heating

Presentation Overview

- Justification as a proposed phytosanitary treatment
- 1D Electro-thermal model of Joule heating process
- Laboratory results on *Pinus radiata* logs
- Flexibility of Joule heating approach – multiple applications
- 3D finite-volume computer modelling of Joule heating
- Production machine and operational costs
- IP and technology roadmap
- Historical Funding and Future Funding requirements

Heating as an alternative to fumigation

- ISPM 15 specifies phytosanitary treatment of wood packaging
- Methyl bromide fumigation or heat treatment are allowed
- Heat requirement is >=56^{o}C, for at least 30 minutes [1]

[1] IPPC. (2009). ISPM 15: Regulation of wood packaging material in international trade. 2013-04 CPM-8 adopted revised Annex 1 to ISPM 15 with consequential changes to Annex 2. Rome, IPPC, FAO. Publication history: Last modified April 2013.

Location and Thermal Tolerance of Pests

- Pest species of concern are within 32mm of log surface [2]
- Most thermotolerant life-stage: eggs of *Arhopalus ferus* [3]
- Eggs of *Arhopalus ferus* killed by 55.56^{o}C for 30 mins [3]

[2] C. Romo et al. (2016). Penetration profile of forest insects into logs. Journal of Economic Entomology. TBC

[3] S. Pawson et al. (2017). Quantifying the thermal tolerance of wood borers and bark beetles for the development of phytosanitary treatments of pine logs. Agricultural and Forest Entomology . TBC

Joule, or Ohmic, Heating

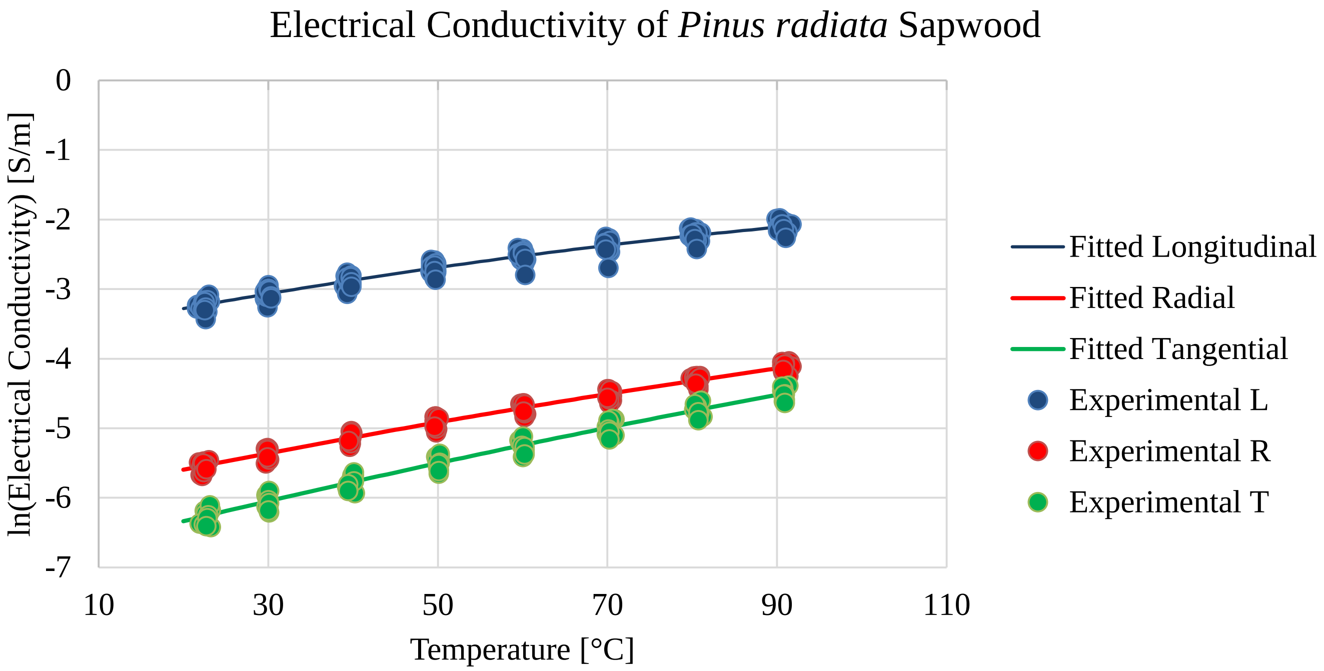
- Joule heating has been found to be technically feasible [4]
- Thermal and electrical properties of *P. radiata* studied [5, 6]
- Electro-thermal model developed to control heating process

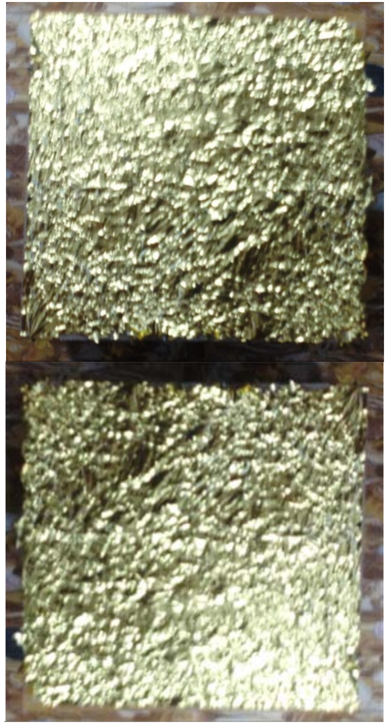
[4] W.J.B. Heffernan (2013). Practical Application of Joule Heating to the Sterilization of Plantation Grown *Pinus radiata* Logs. NZ Electricity Engineers Association Conference, Auckland. June 2013.

[5] S. Pang et al. (1995). Modelling the temperature profiles within boards during the high-temperature drying of *Pinus radiata* timber: the influence of airflow reversals. International Journal of Heat and Mass Transfer 38(2):189–205

[6] N. Nursultanov et al. (2017). Effect of temperature on electrical conductivity of green sapwood of *Pinus radiata* (radiata pine). Wood Science and Technology. DOI 10.1007/s00226-017-0917-6

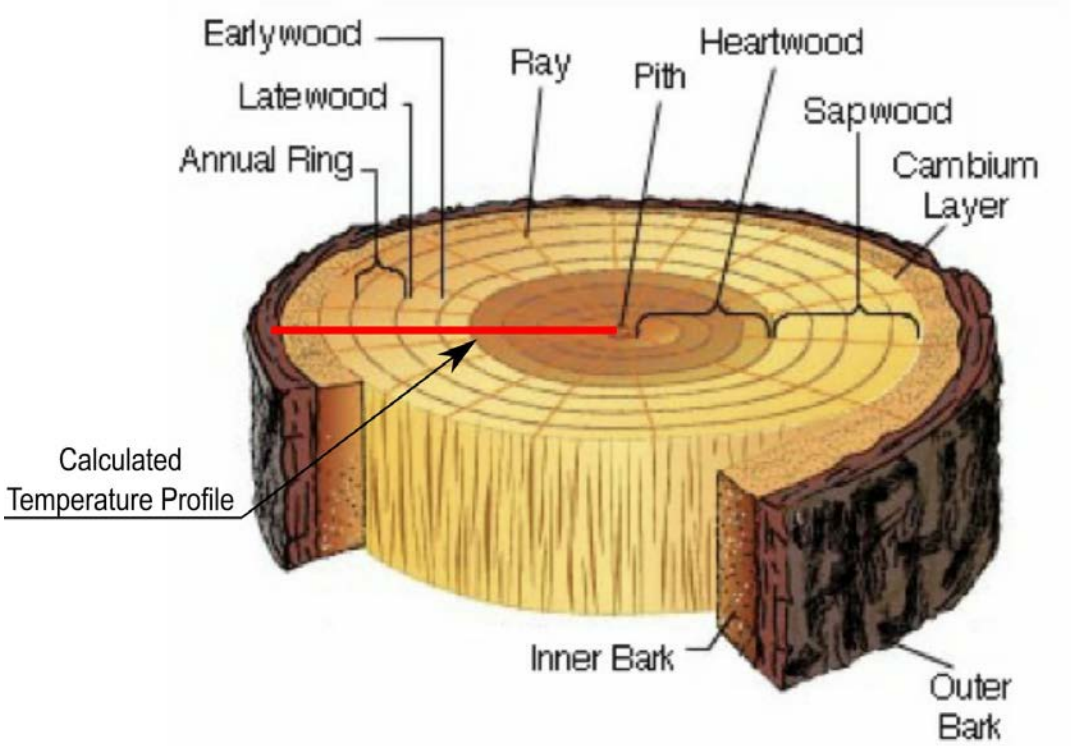
Anisotropic Electrical Behaviour of *P. radiata*





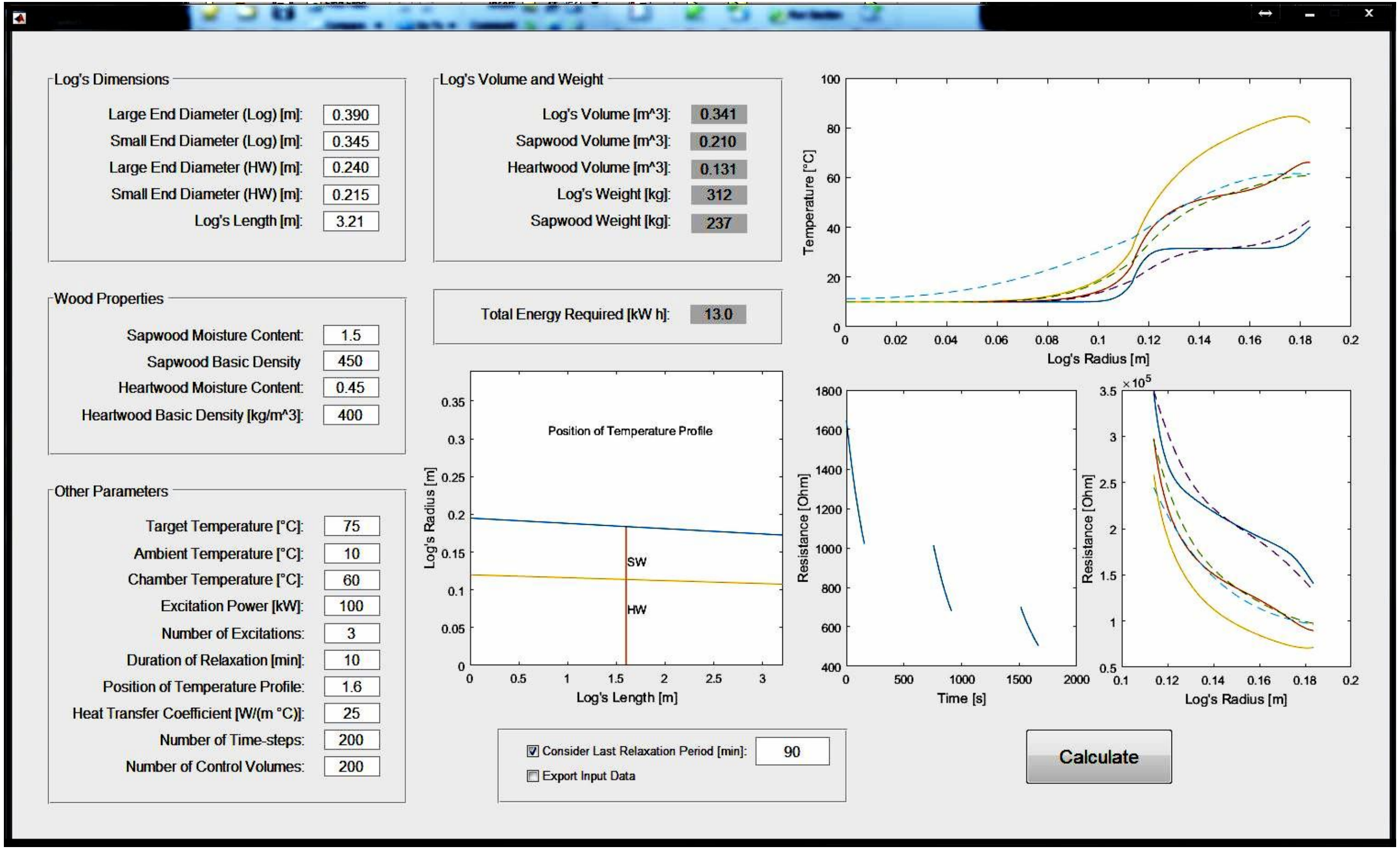
Anisotropic Electrical Conductivity of *P. radiata* versus Temperature

Simplified Electro-thermal model

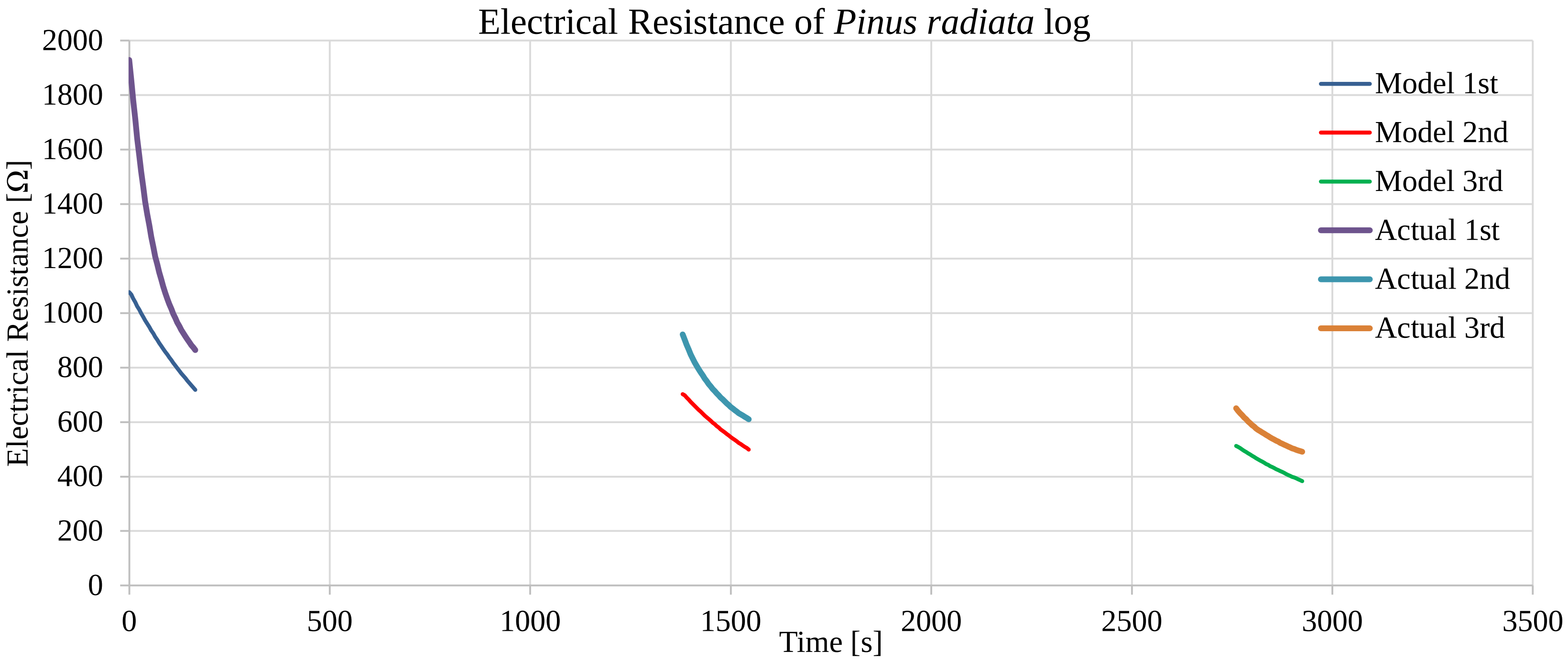


Original picture: Vagra

Simplified Electro-thermal model



Simplified Electro-thermal model

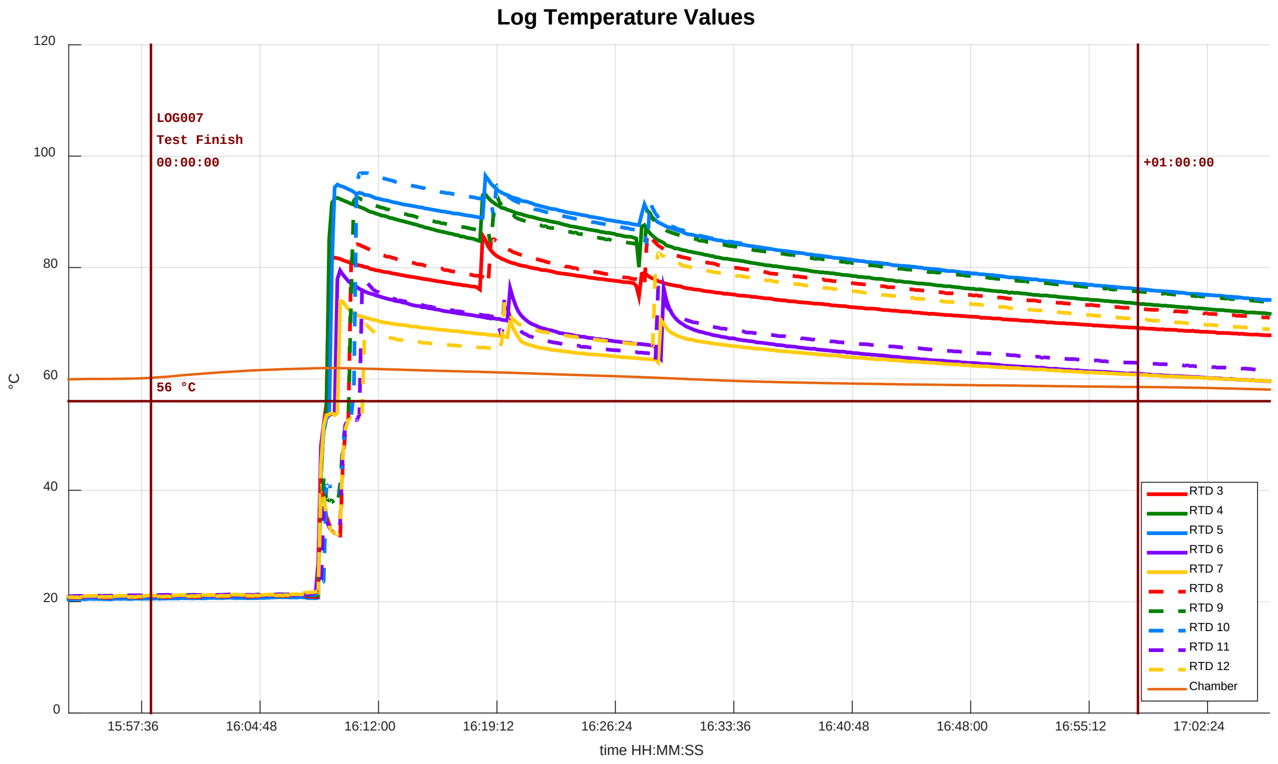


Comparison of modelled and measured log resistances for LOG008

Experimental laboratory results

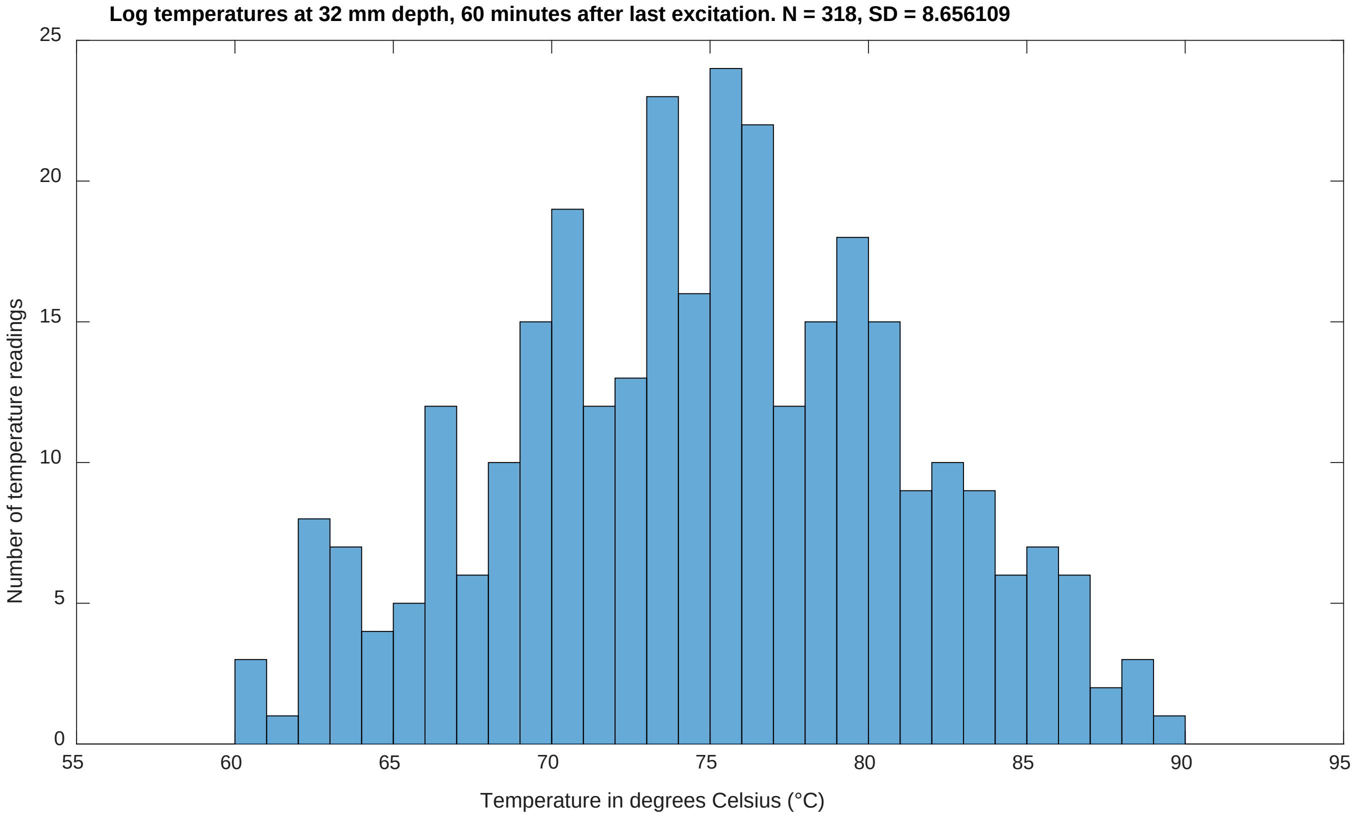
- 32 test logs, 3.2m long, SED and LED in range 30 to 45cm
- Logs Joule heated according to electro-thermal model
- 30 temperature locations in each log; all meet ISPM 15
- 10 logs infested with *H. ligniperda;* all life-stages destroyed

Typical Single Log Temperatures



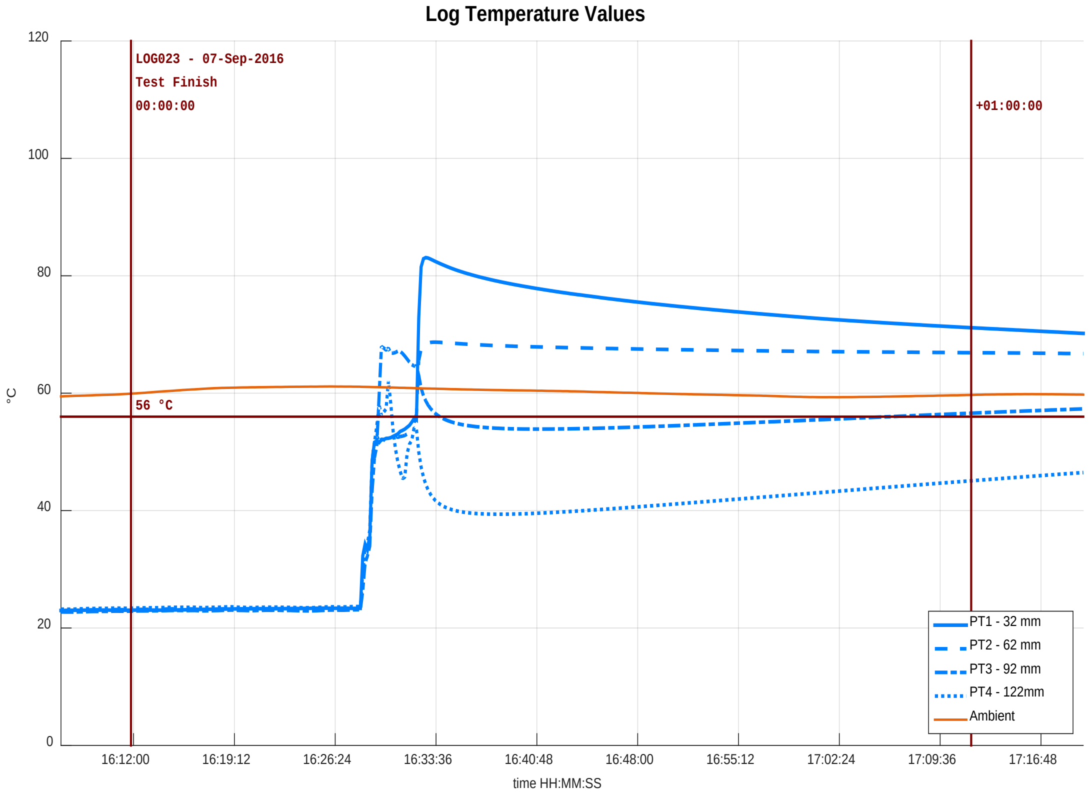
Temperatures measured at 30 locations (3 sets of 10 locations, each 32mm below cambium), in the hour following Joule heating of a typical test log

Range of Log Temperatures

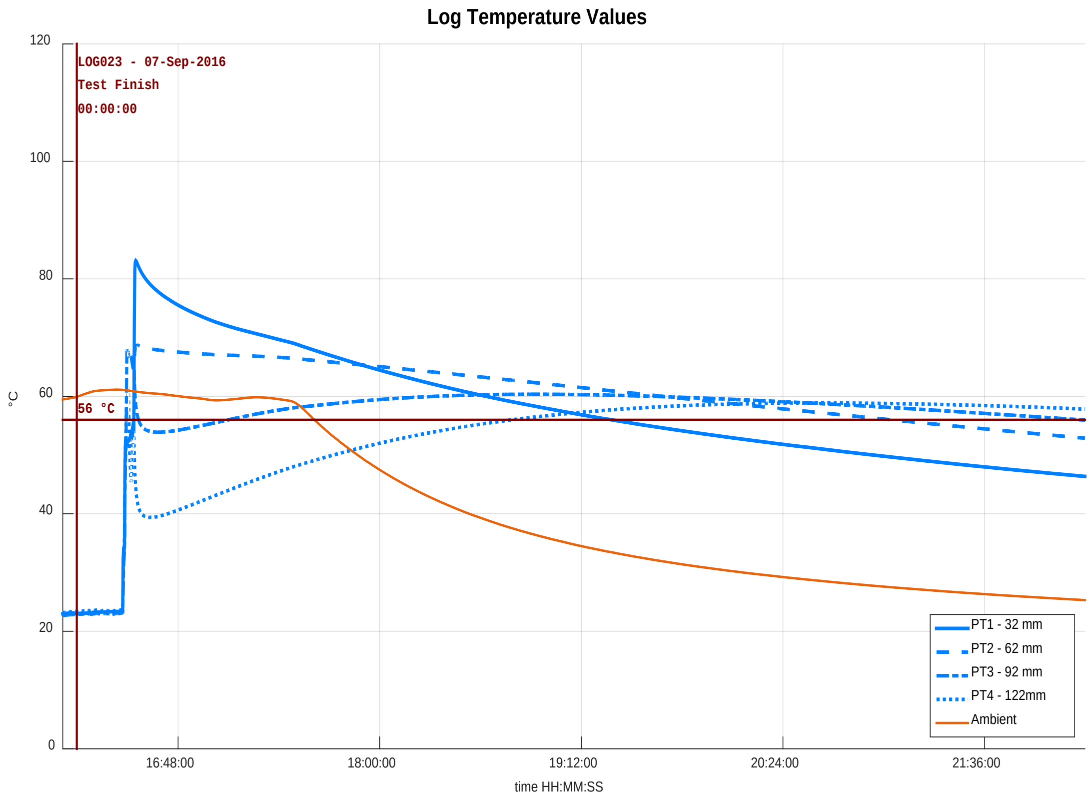


Temperatures measured at the final set of 10 locations, over 32 test logs, 30 to 60 minutes after Joule heating of each log. All temperatures exceed ISPM 15 requirements

Typical temperature profile through log – short timescale



Typical temperature profile through log – extended timescale

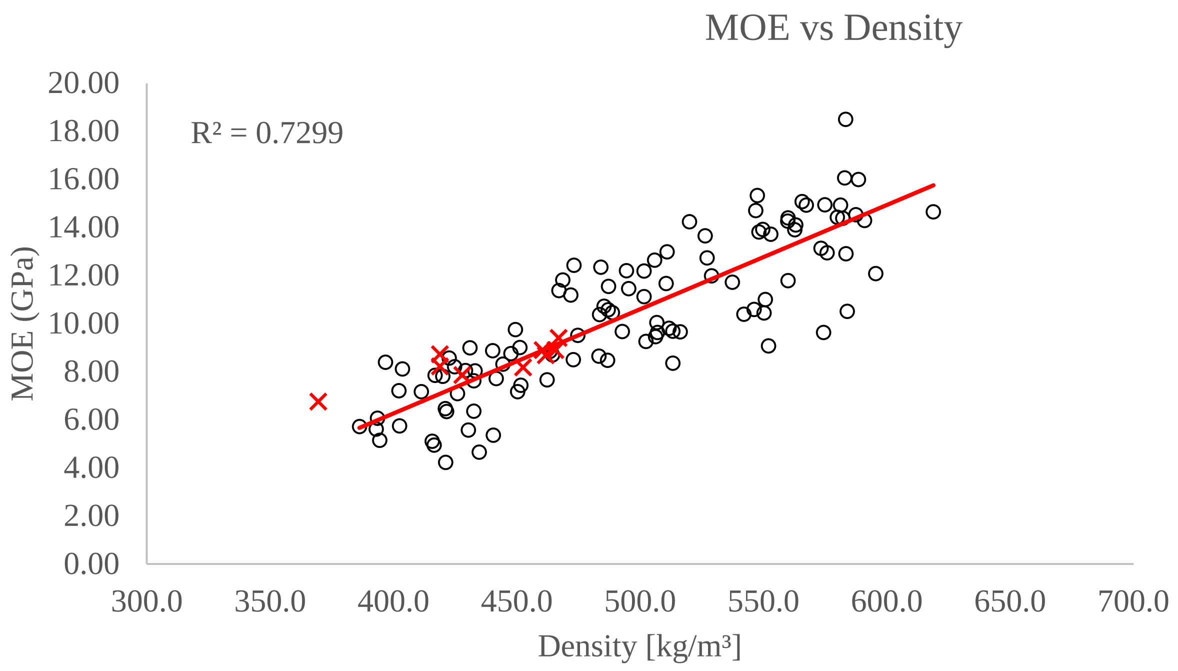


Treated Timber Inspection

Timber being processed:

- Discs for **DiscBot** scanning at Scion, Rotorua, in plastic bags and on mat
- Sections for milling and strength testing, in Forestry and Civil Engineering, to left of photograph
- Waste wood and sawdust to right

Timber Strength Testing



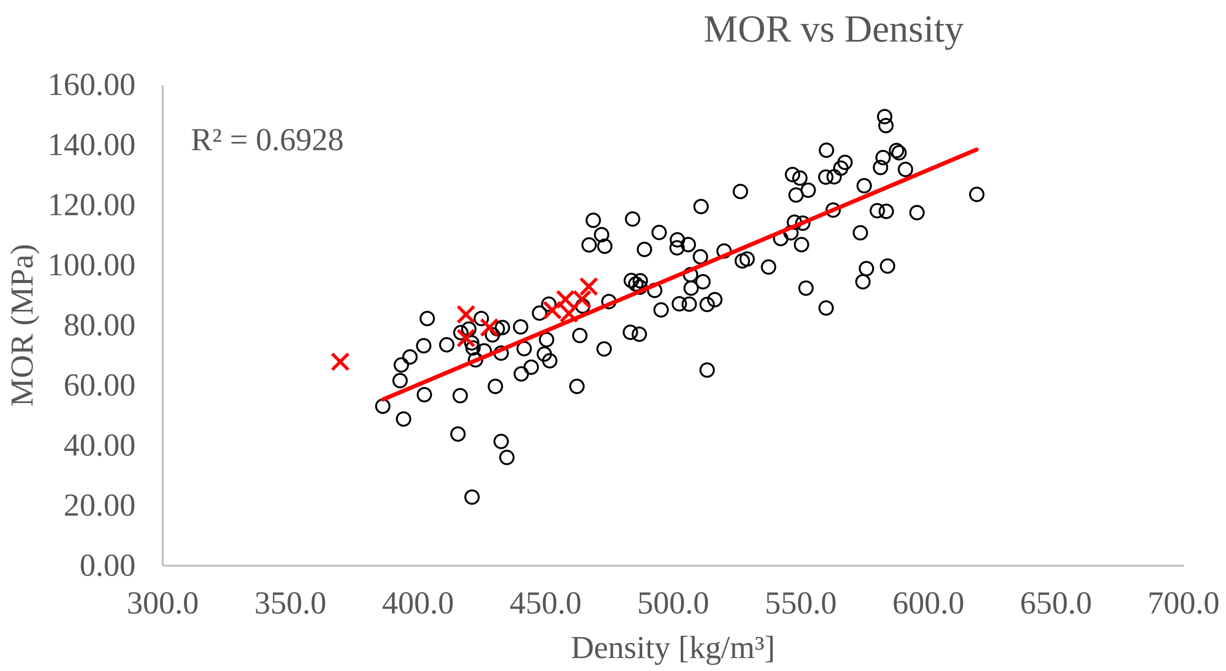
Measured Modulus of Elasticity versus Density (black circles)

Best fit straight line (red line)

Published Data (red crosses) [3]

Strength has not been compromised by Joule heating

Timber Strength Testing



Measured Modulus of Rupture versus Density (black circles)

Best fit straight line (red line)

Published Data (red crosses) [3]

Strength has not been compromised by Joule heating

Flexibility of Joule heating approach

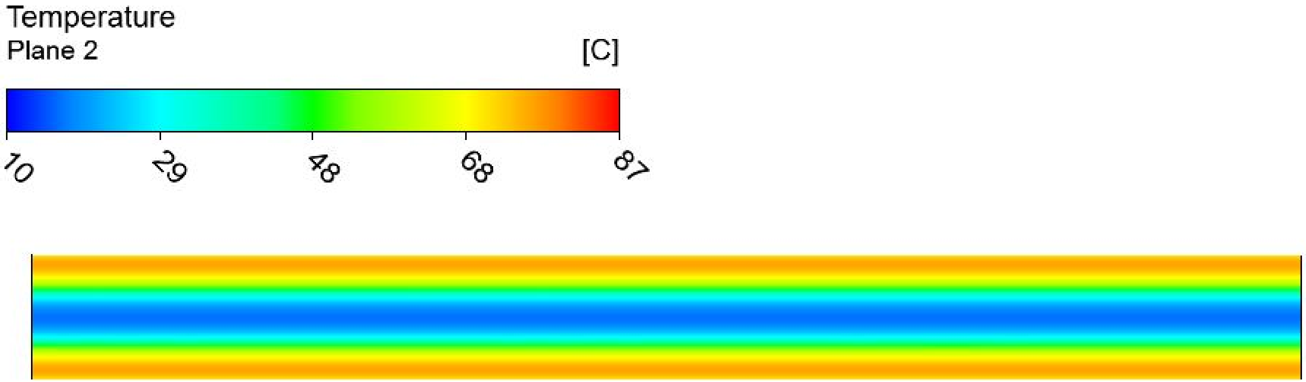
- Process can be tailored for temperature profile
- May be used against emergent insects/pathogens
- Full thermal data for every log; easy compliance monitoring
- Fast, relatively inexpensive and efficient [7]

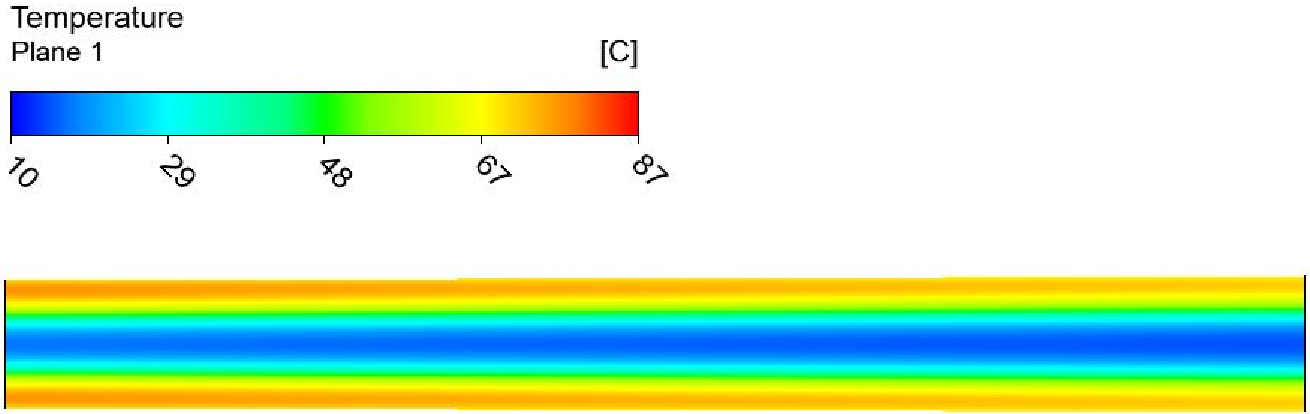
[7] P. Perré (2004). Electrical heating of green logs using Joule's effect: a comprehensive computational model used to find a suitable electrode design. Wood Science and Technology 38(6):429–449

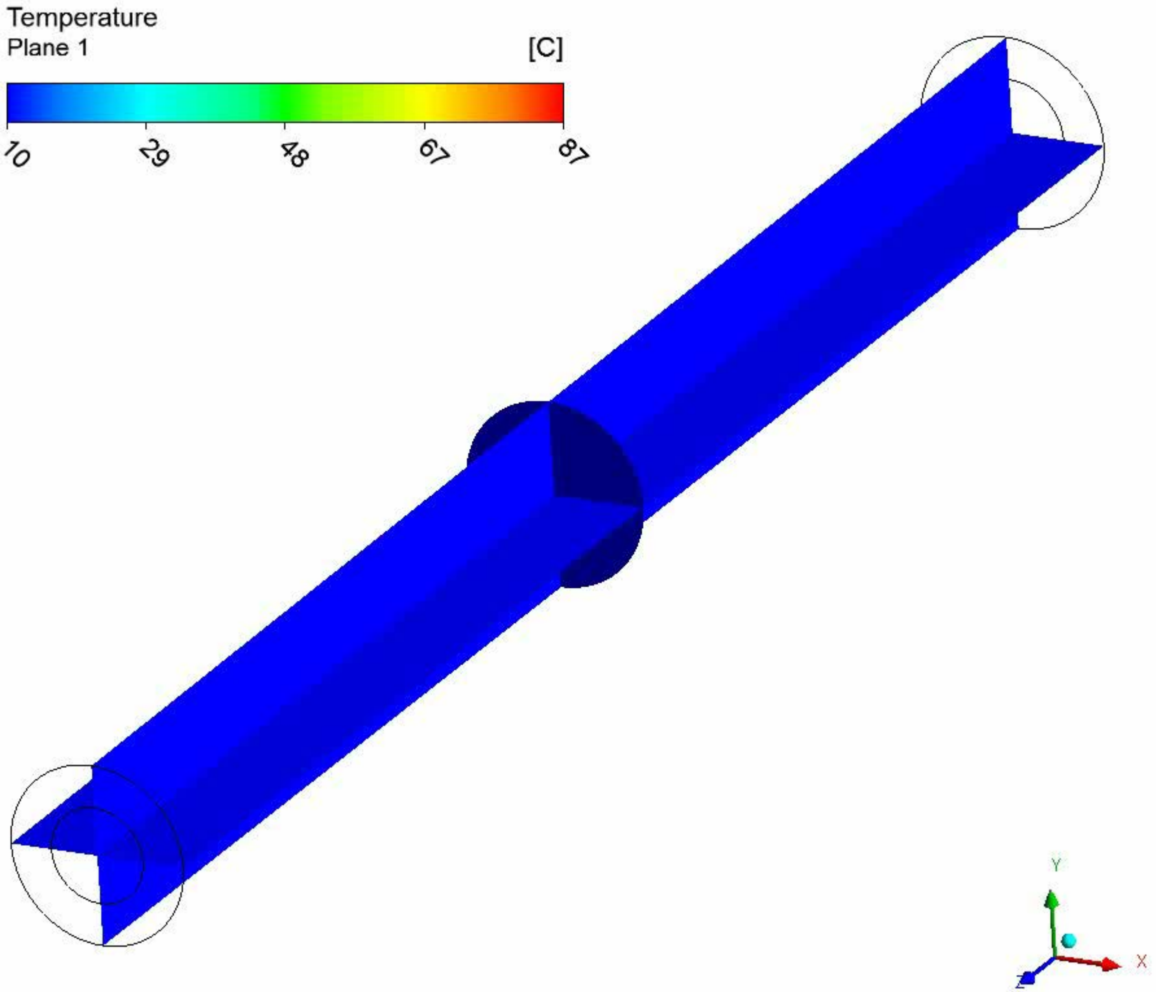
Flexibility of Joule heating approach

- Process can be tailored for other timber species
- May be used against fungi (e.g. sapstain) as well as insects
- Can be readily modelled in simplified 1D or full 3D forms
- Applicable to plywood and LVL manufacture
- May be applicable to log thawing and densification

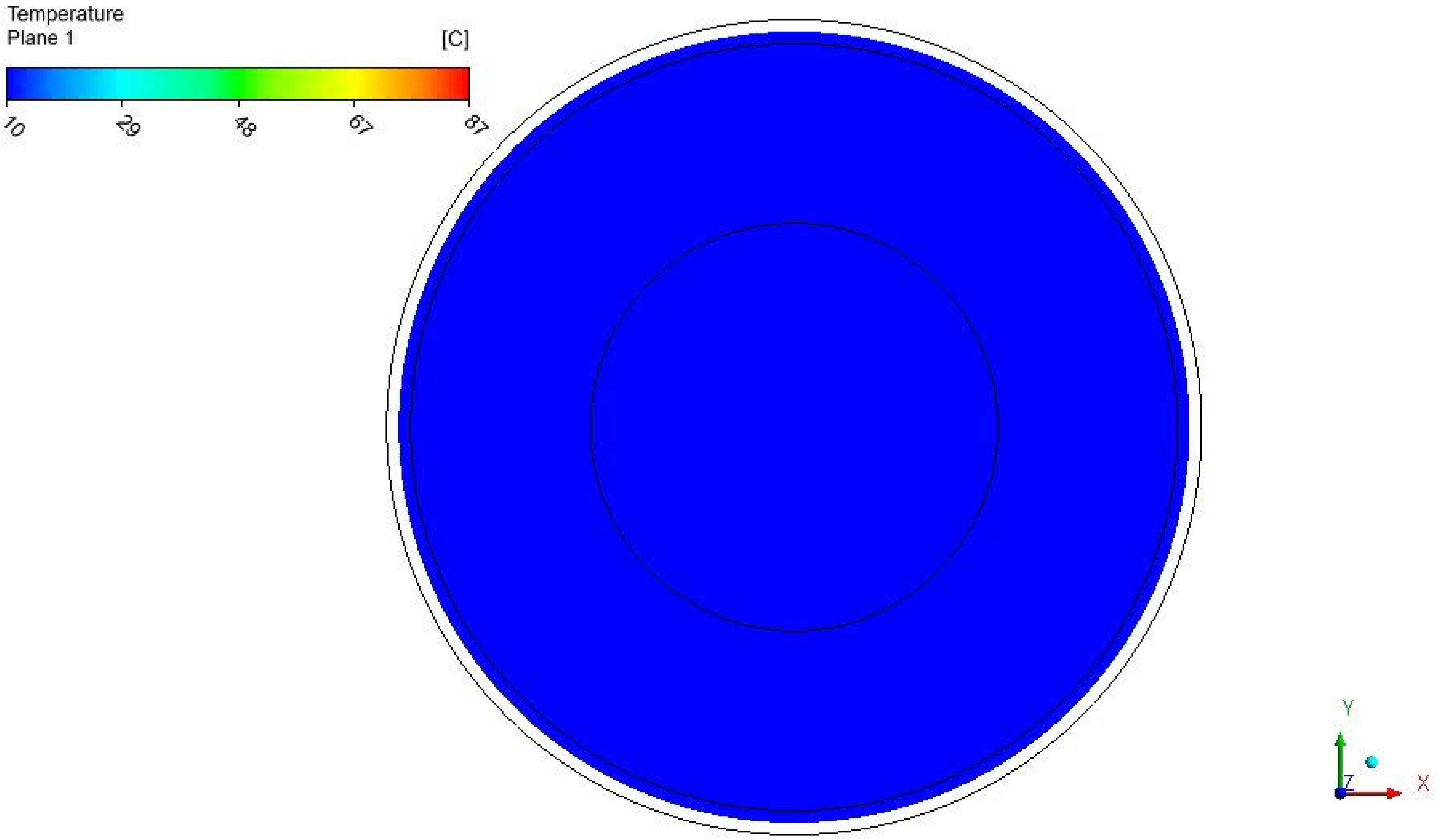
3D CFD Modelling

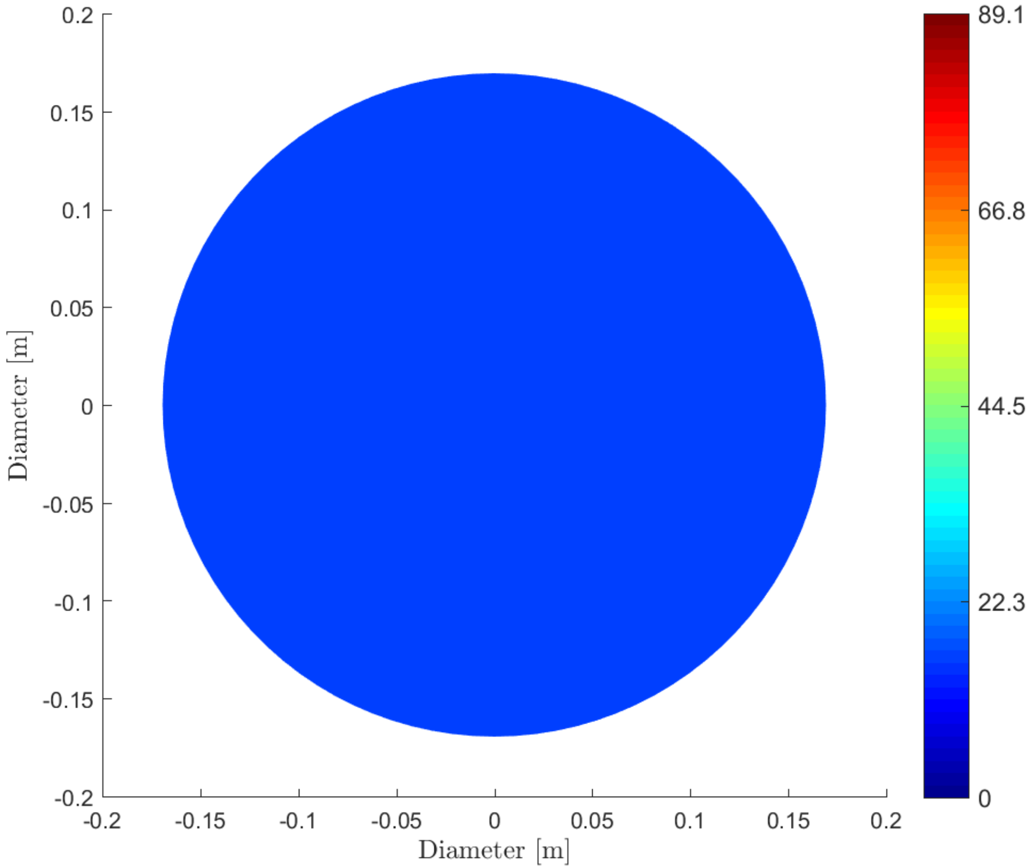






Temperature
Plane 1
[C]
10
29
48
67
87
Y
X
Z


Temperature
Plane 1
[C]
10
29
48
67
87
Y
Z
X


0.2
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Diameter [m]
-0.2
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Diameter [m]
89.1
66.8
44.5
22.3
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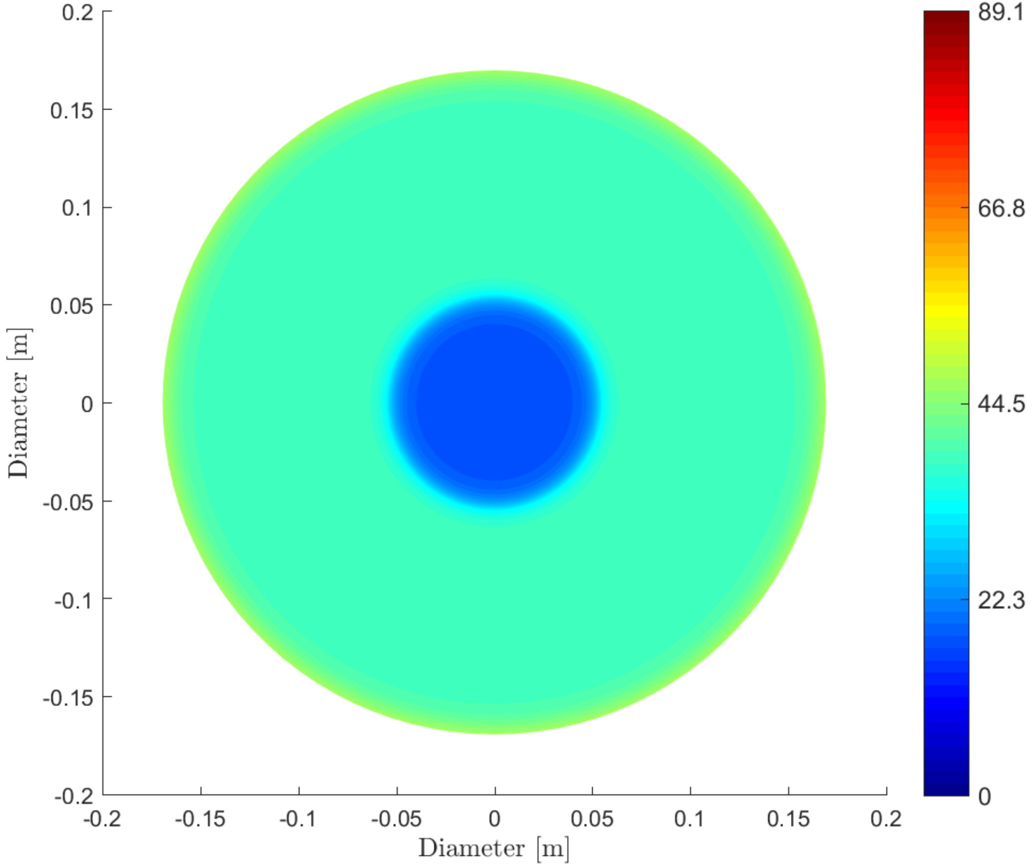

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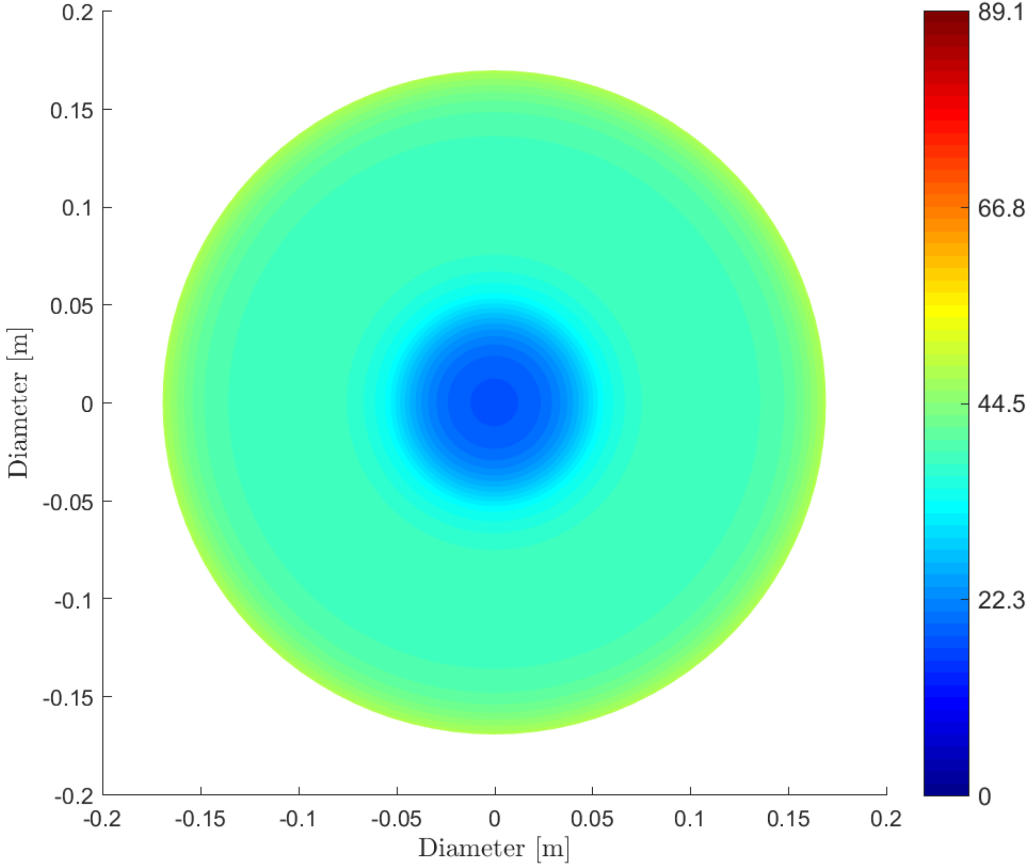

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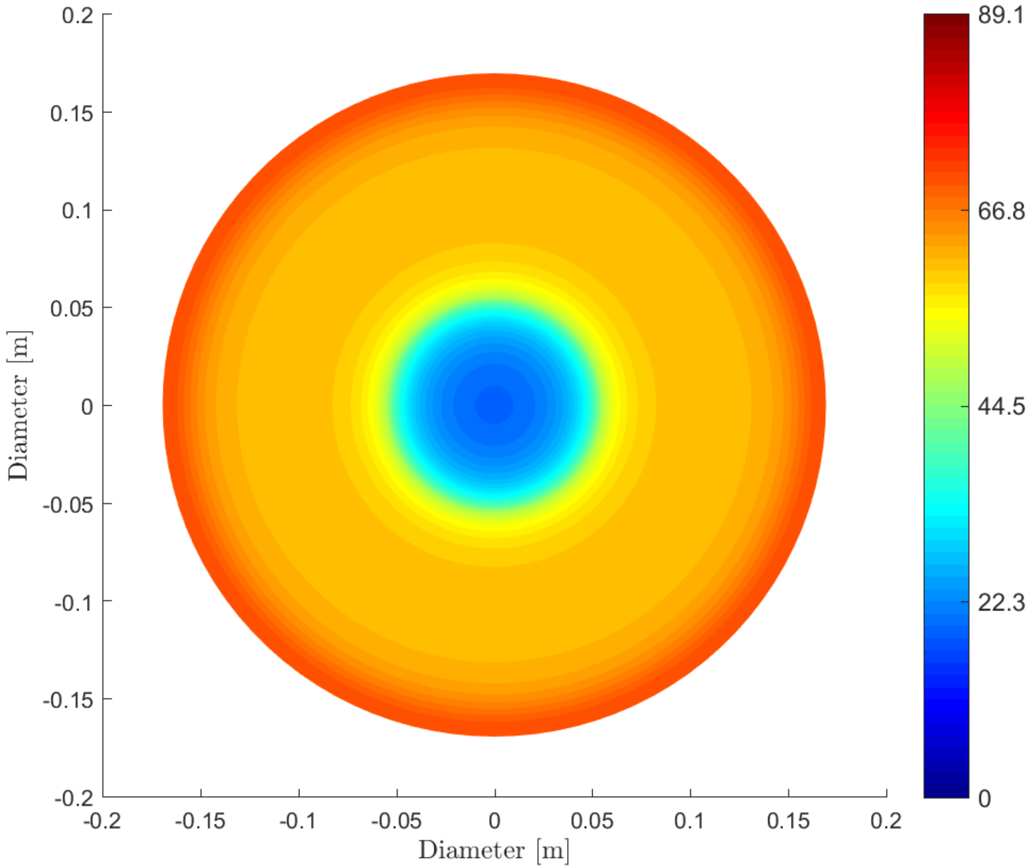
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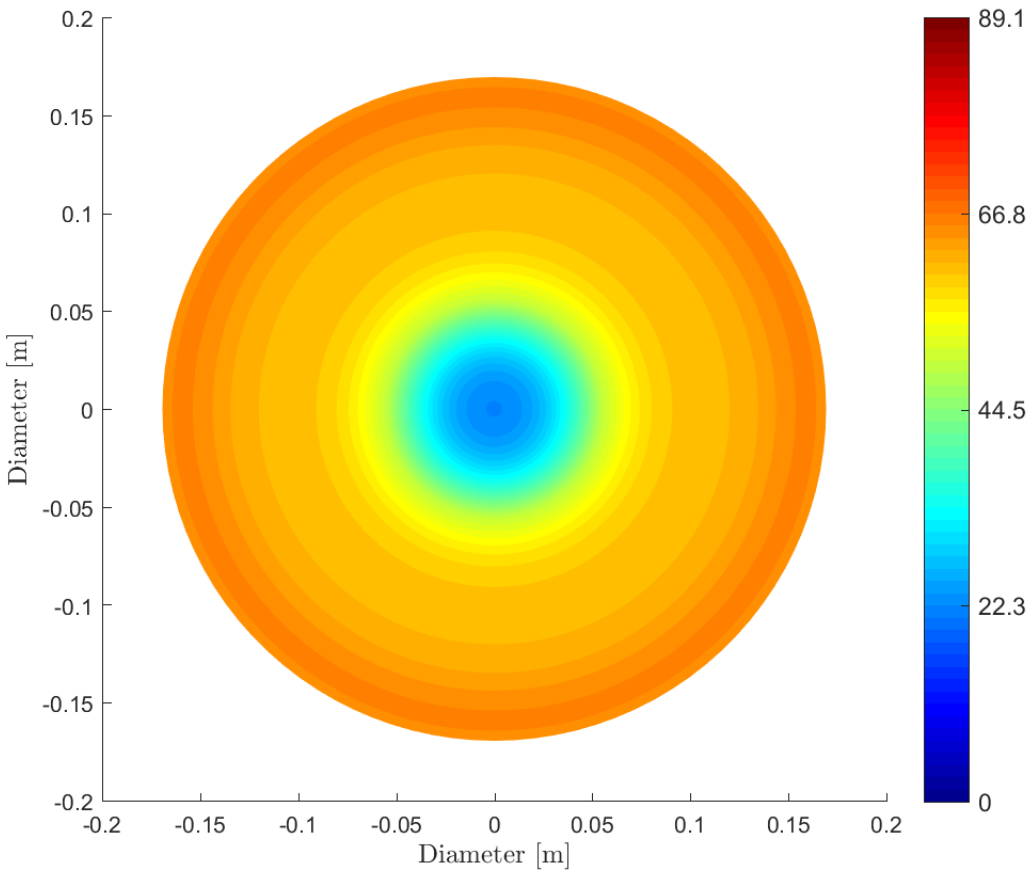

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Diameter [m]
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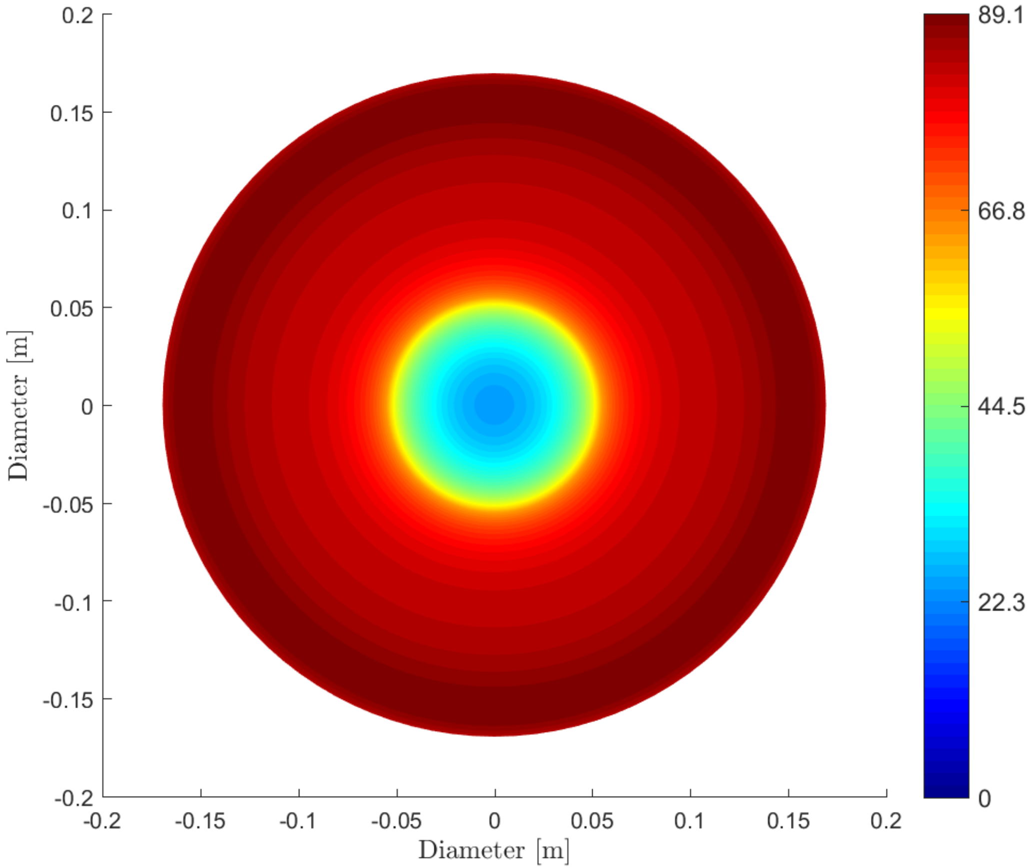
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Diameter [m]
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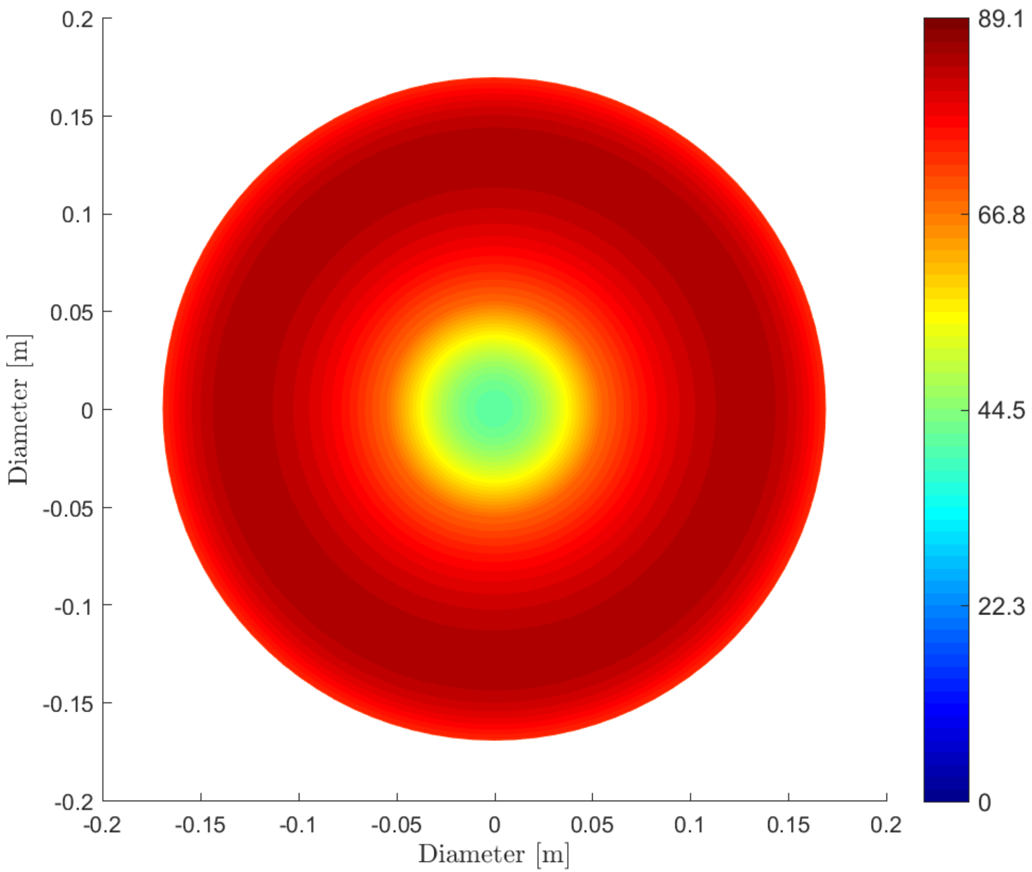

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Diameter [m]
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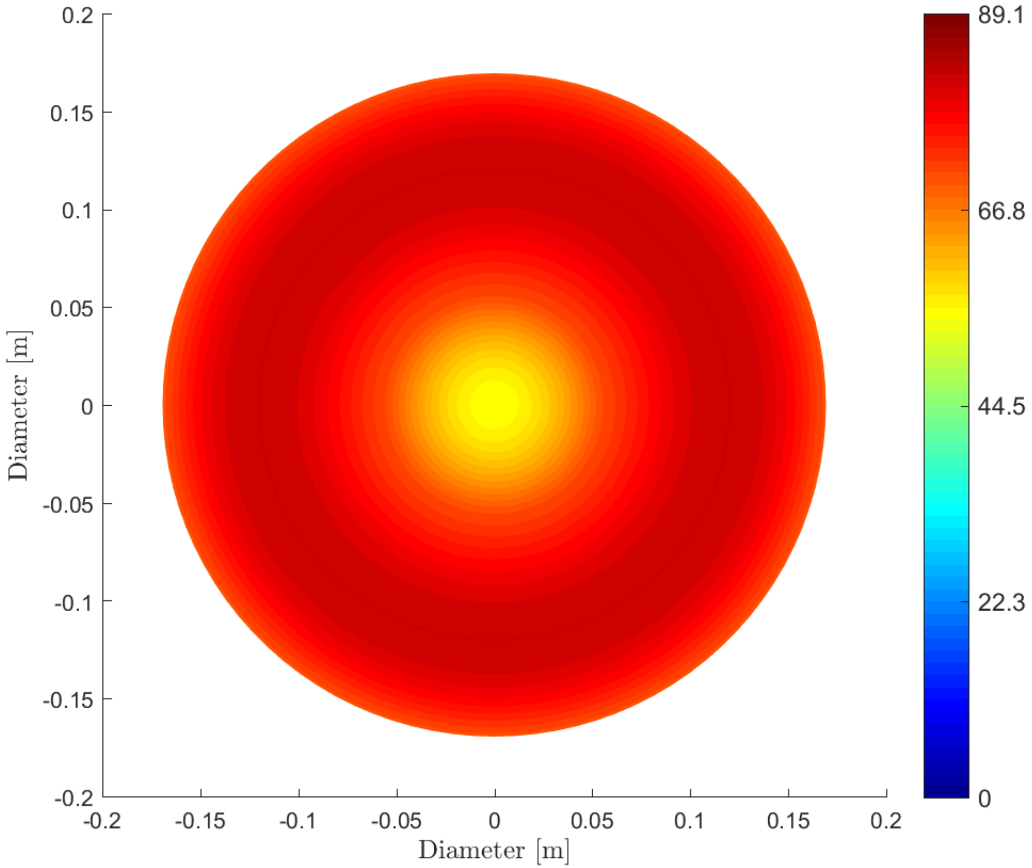
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Diameter [m]
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0.2
Diameter [m]
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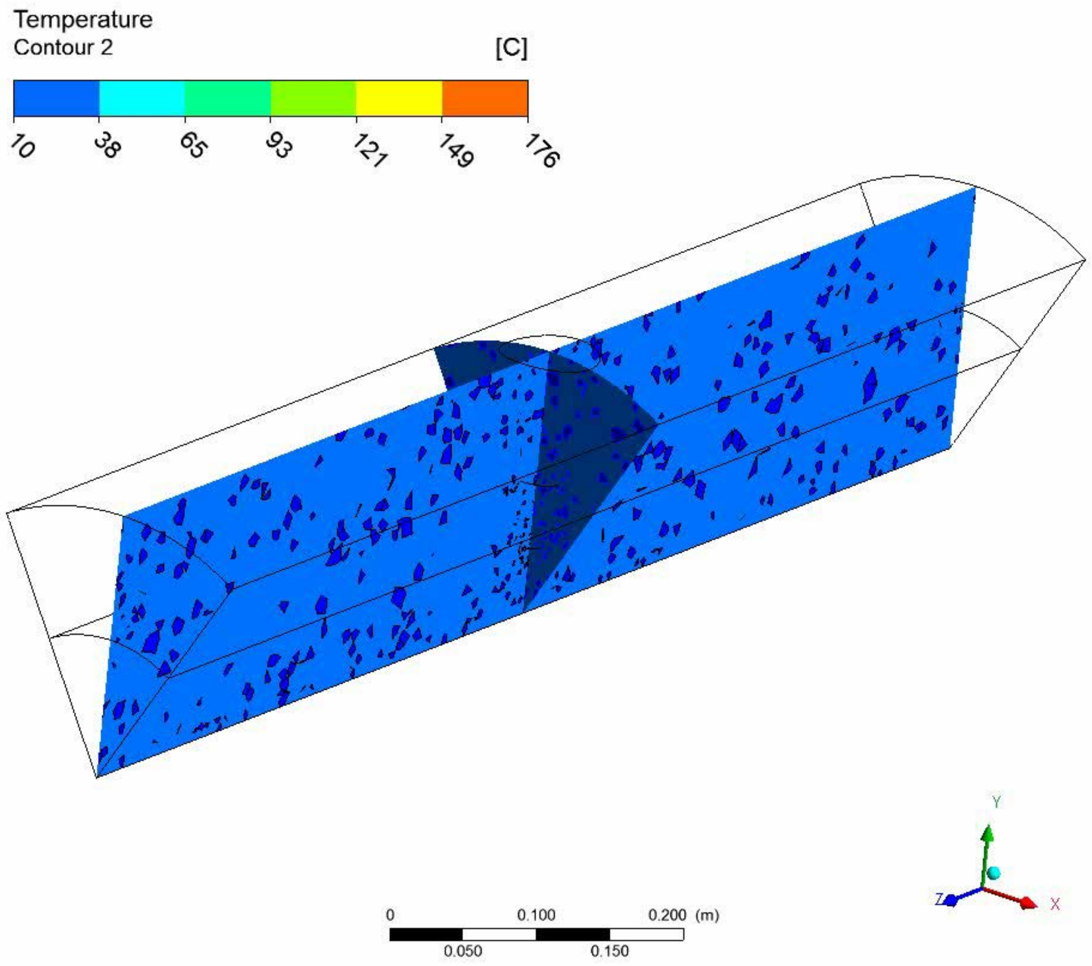
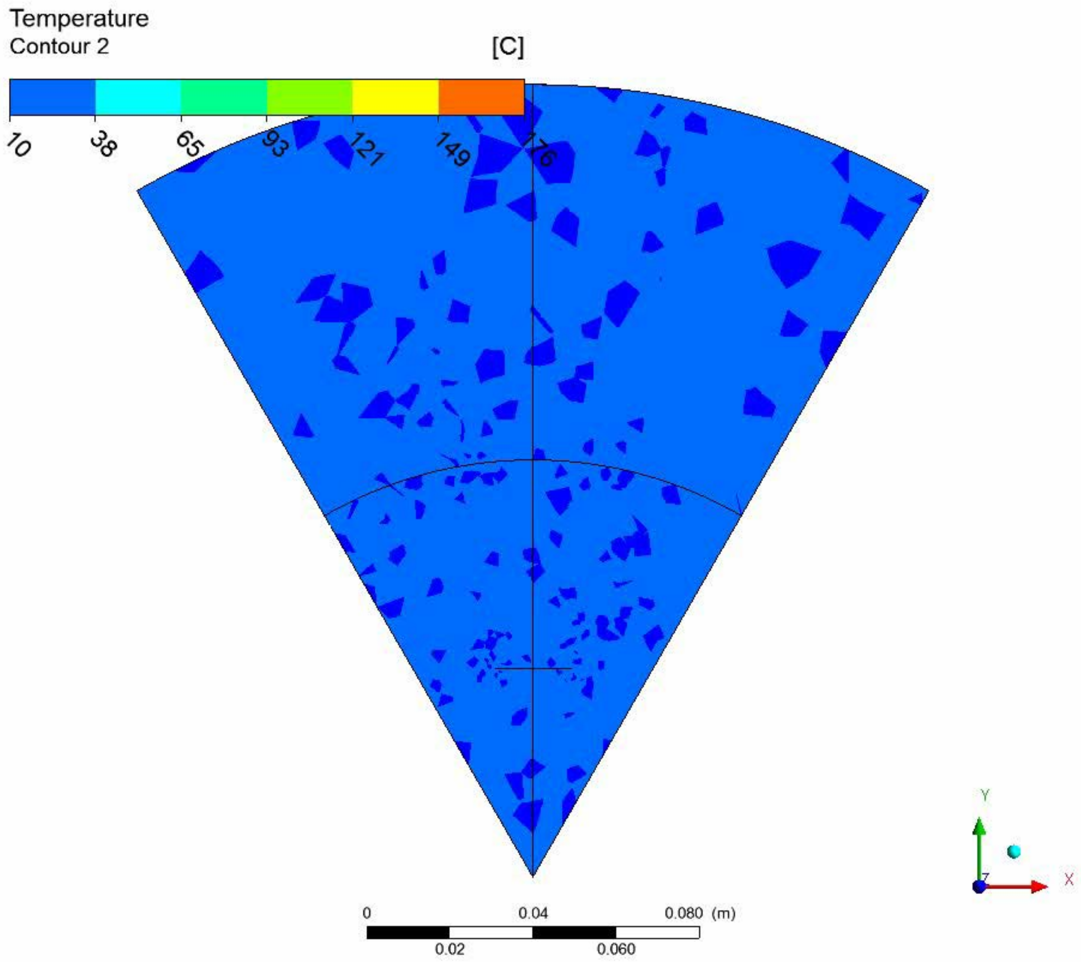
66.8
44.5
22.3
0


Temperature
Contour 2
[C]
10
38
65
93
121
149
176
0
0.100
0.200 (m)
0.050
0.150
Y
Z
X


Temperature
Contour 2
[C]
10
38
65
93
121
149
176
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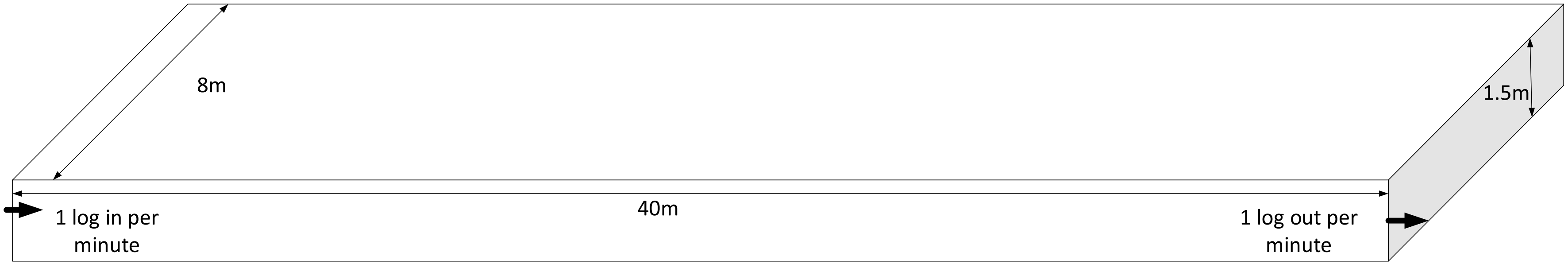
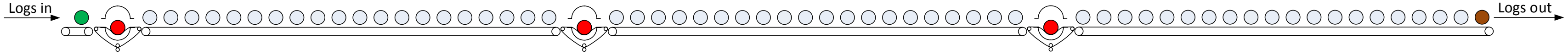
0.04
0.080 (m)
0.02
0.060
Y
X

Modular Conveyorized Heating Line

Single 1MW low profile unit



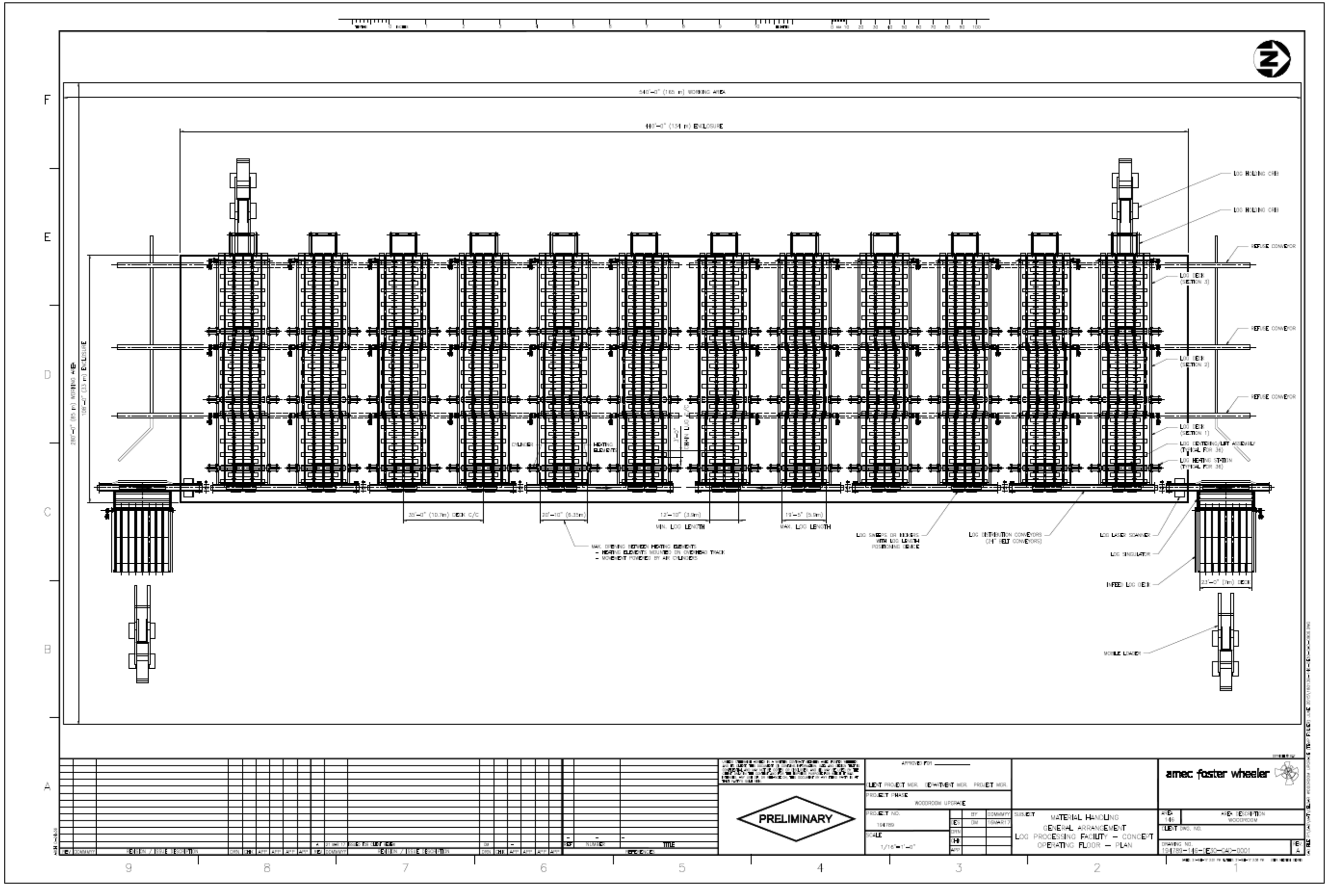


Fresh green logs are measured for LED, SED, HWLED, HWSED, length and mass

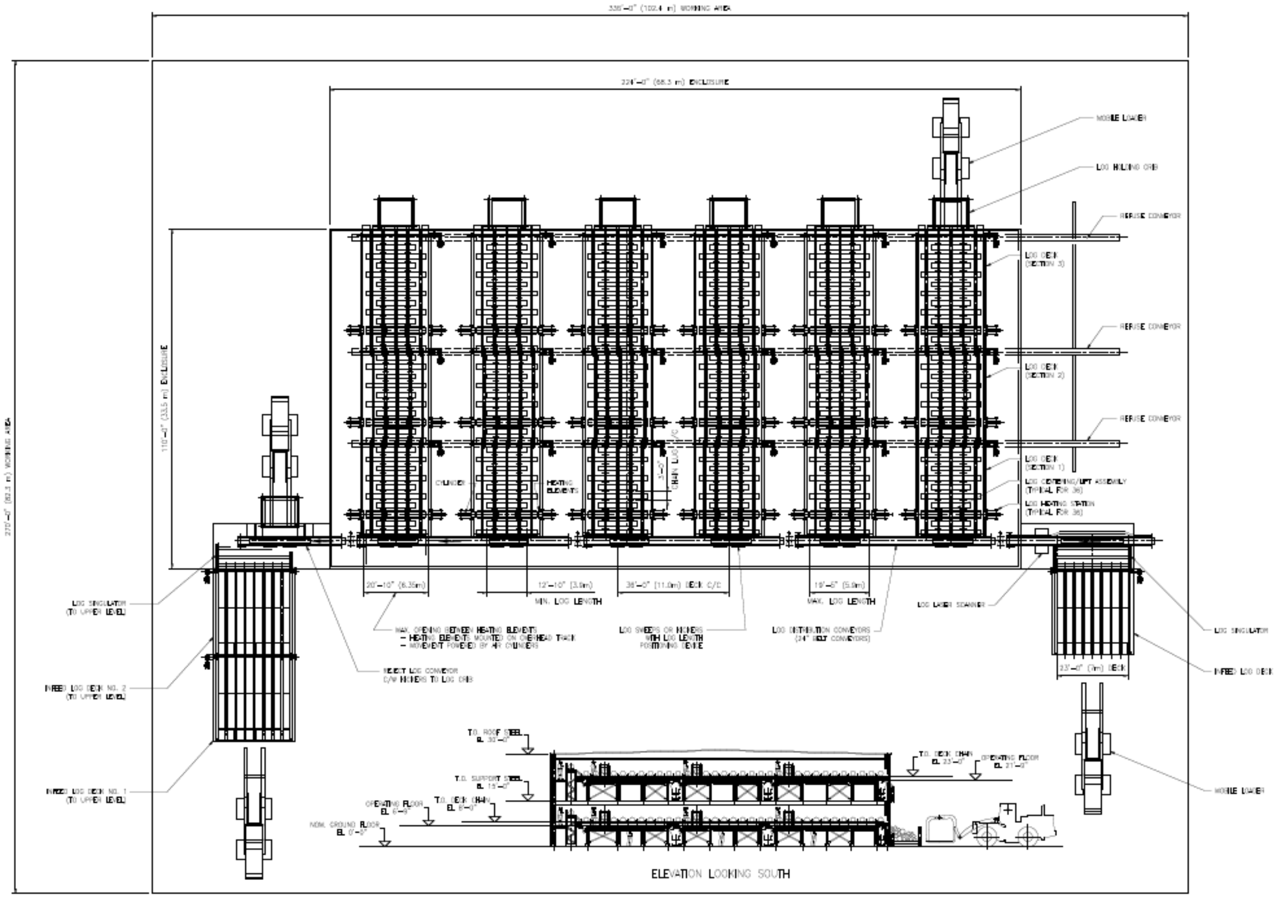
Power is applied to red logs in heating chambers

Heat treated brown logs leave the conveyor 1 hour after entering

2.1M JASm^3 capacity per annum - Single Tier Arrangement

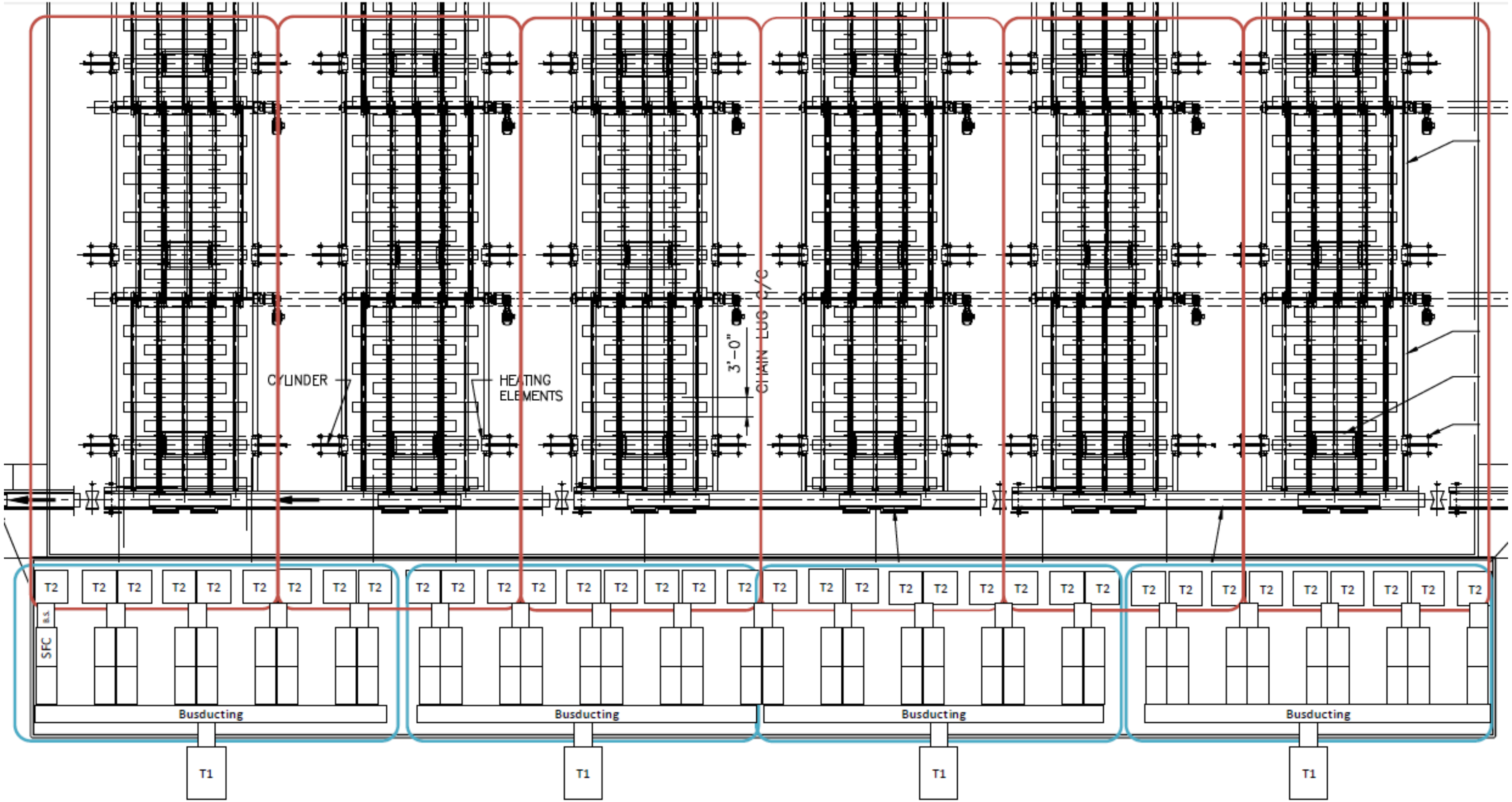


Two Tier Arrangement



Two Tier Footprint

Electrical Equipment



Finance Costs +/- 50%

Plant Cost = $86M

- Finance: $3.18/JAS (7% WACC, 25 Years)
- **Treatment:** **$9.84/JAS** (8c/kWh fixed contract)

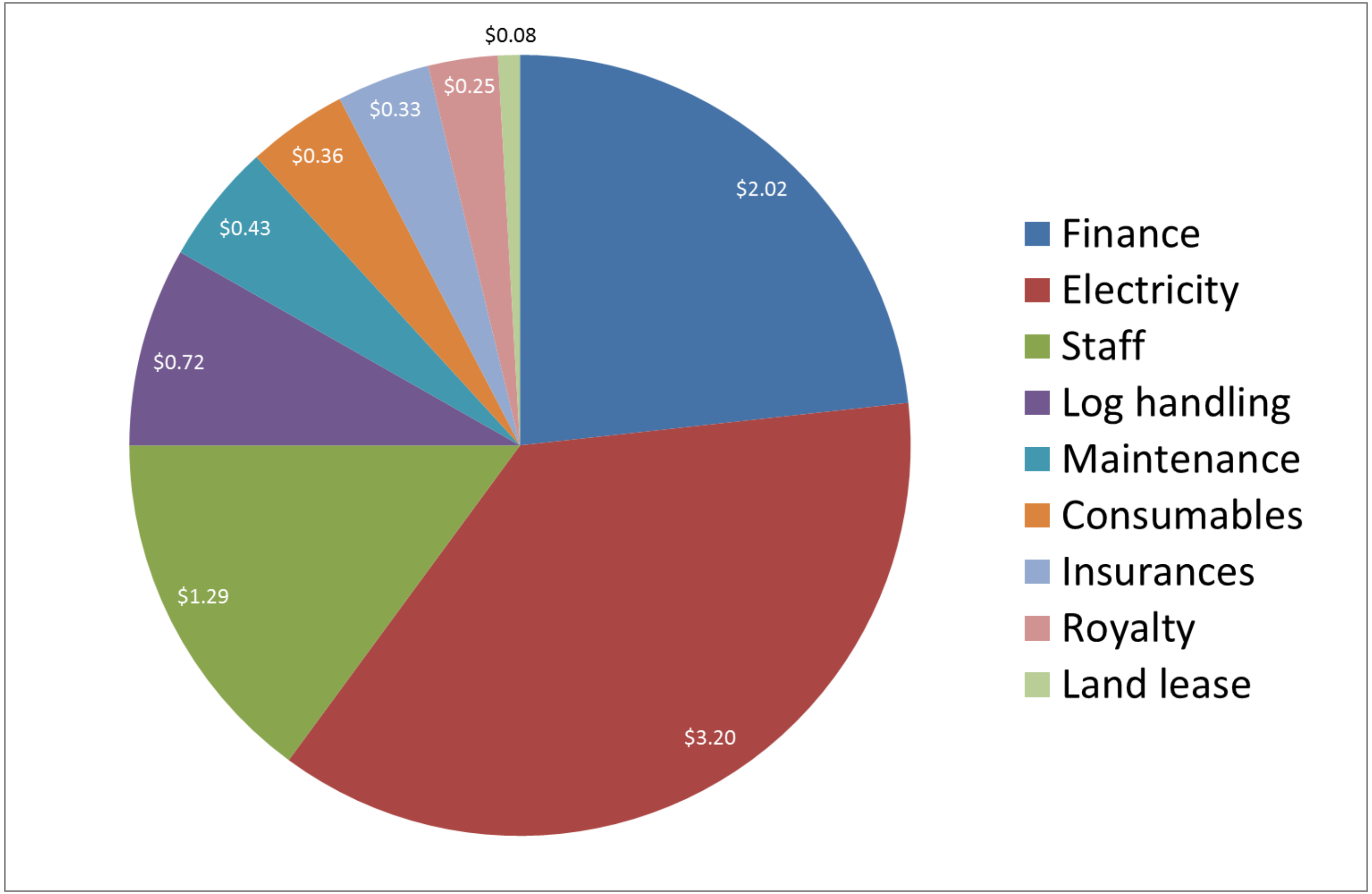
Plant Cost = $57M

- Finance: $2.02/JAS (7% WACC, 25 Years)
- **Treatment:** **$8.68/JAS** (8c/kWh fixed contract)

Plant Cost = $29M

- Finance: $0.87/JAS (7% WACC & 25 Years)
- **Treatment:** **$7.53/JAS** (8c/kWh fixed contract)

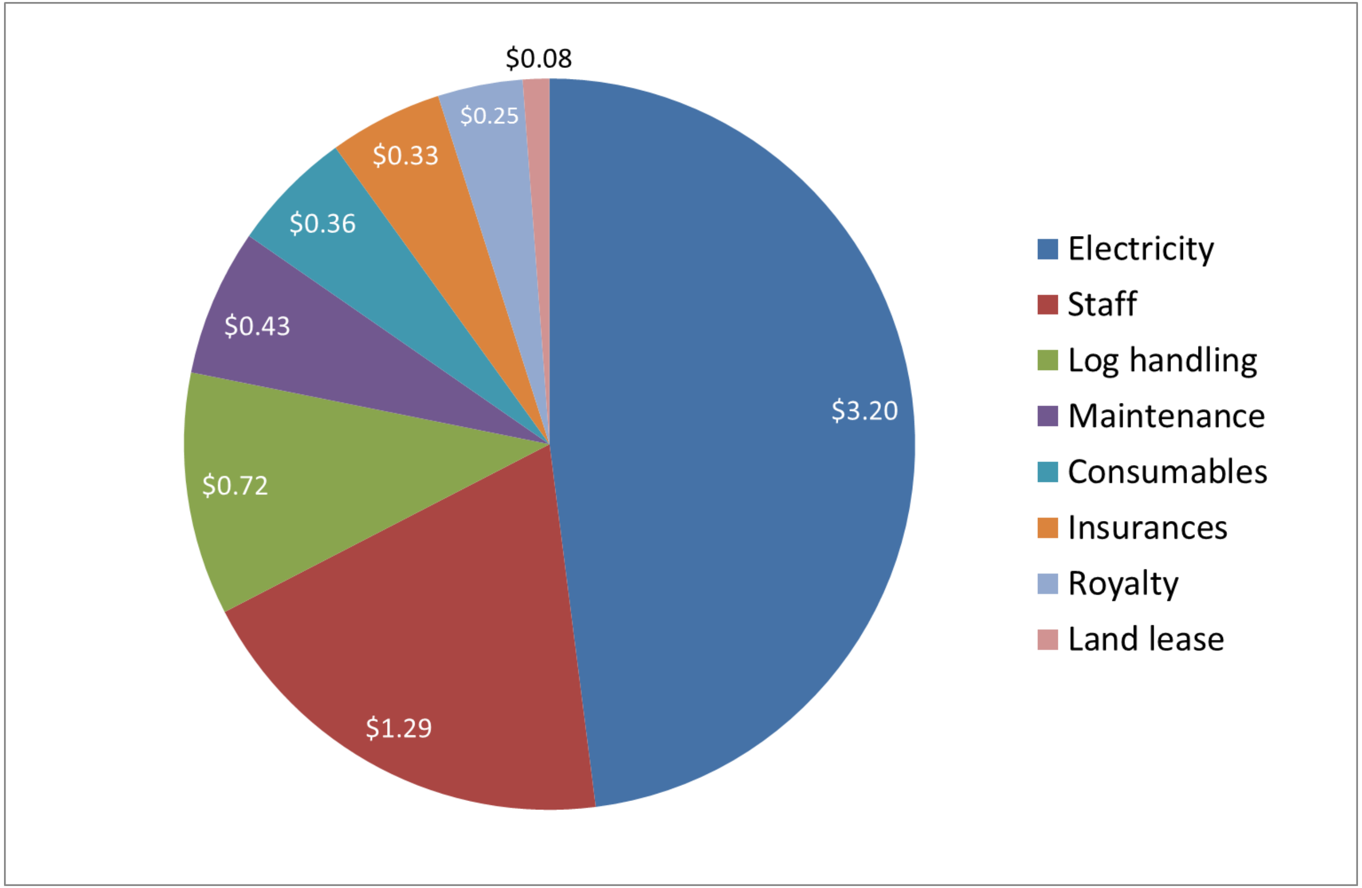
Total Costs – $57M, 38kWh/JAS, 8c/kWh



$2.02
$3.20
$1.29
$0.72
$0.43
$0.36
$0.33
$0.25
$0.08
$8.68/JAS

Fixed Contract

Operating Costs – 38kWh/JAS, 8c/kWh



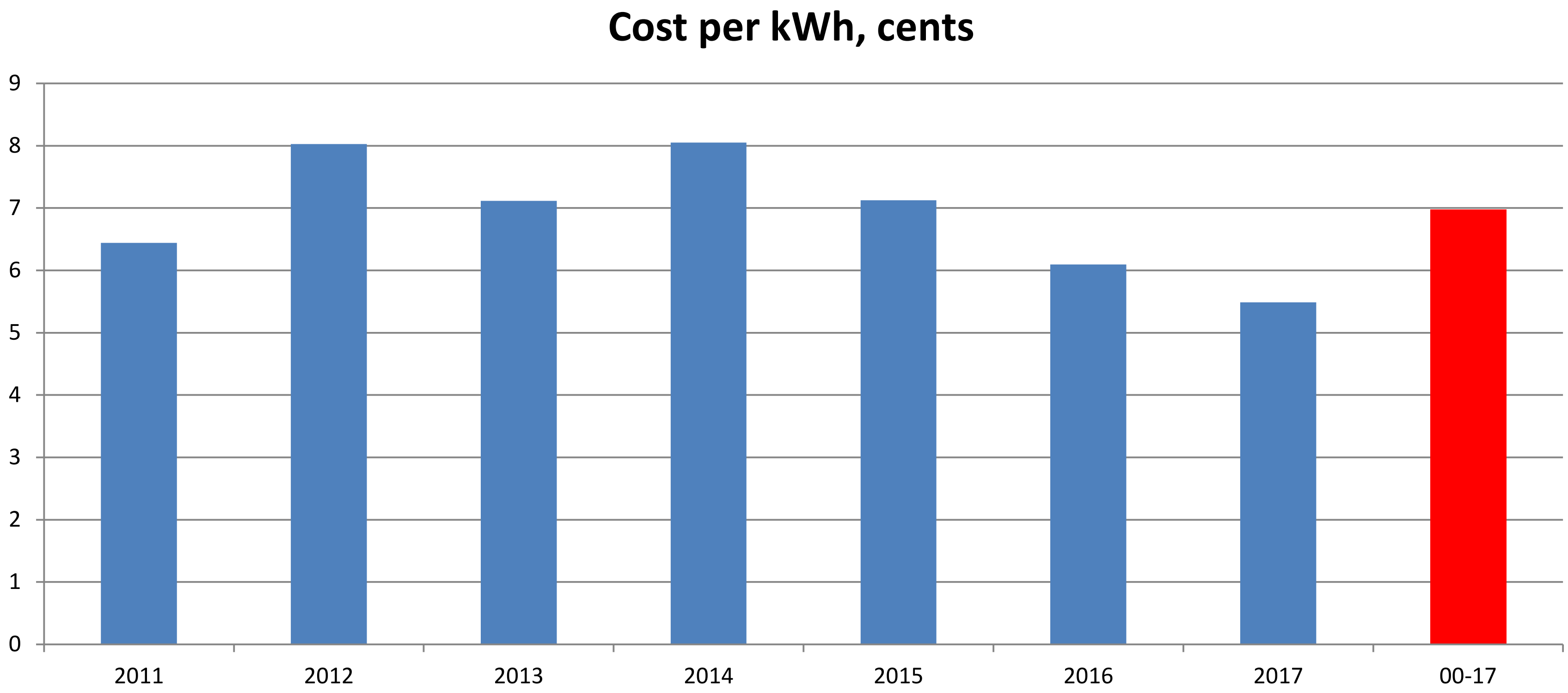
$3.20
$1.29
$0.72
$0.43
$0.36
$0.33
$0.25
$0.08
$6.66/JAS

Fixed Contract

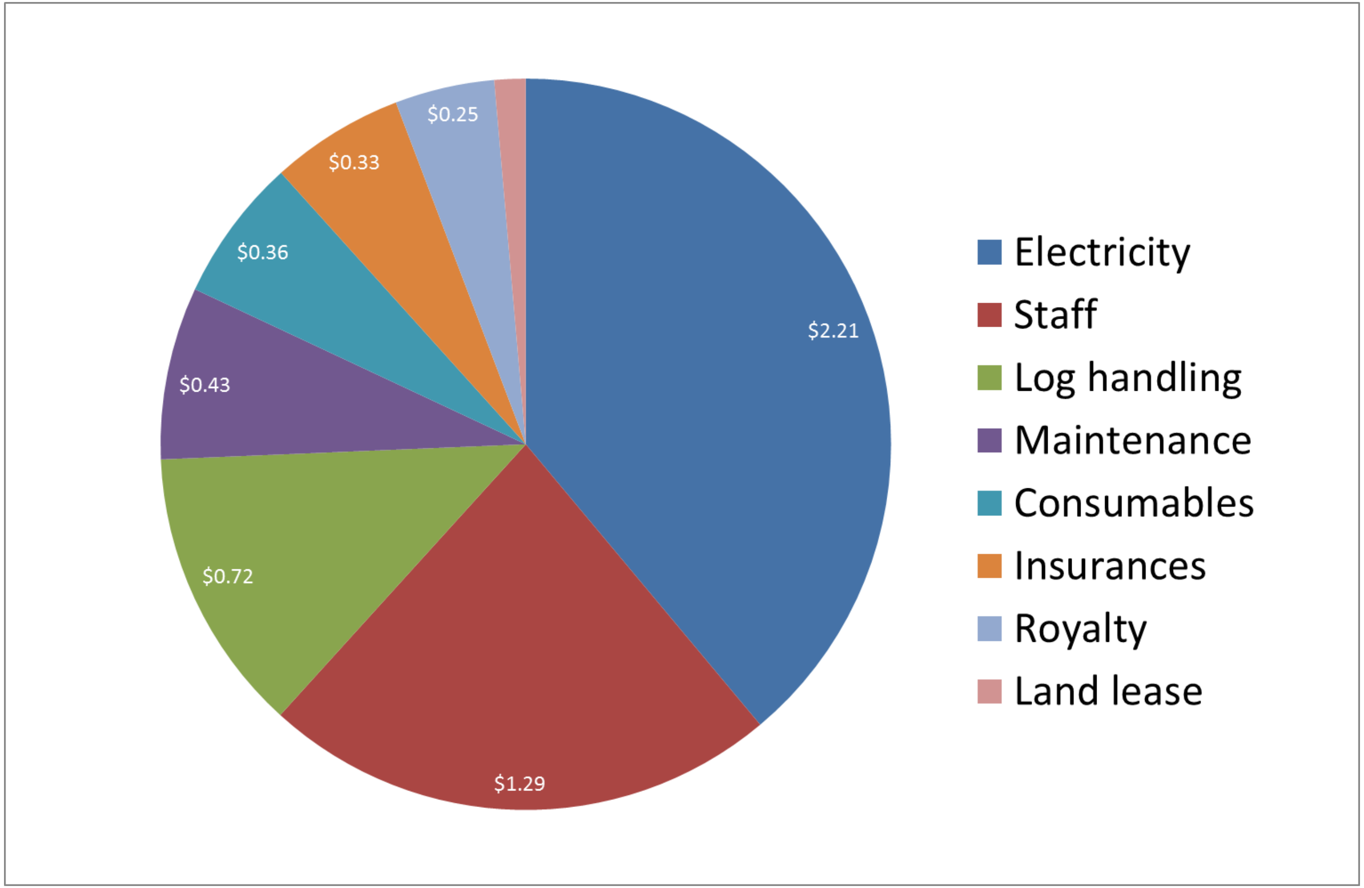
Managing electricity costs

- Obtain best fixed price deal – 8c/kWh - safe, but a price to pay
- Take spot market option – best price on average, at some risk
  - 5.5c/kWh average spot price 2016-2017
  - In a dry year price rises around June to August are possible
  - Transmission constraints due to temporary line outage can increase price
- Reduced energy, kWh/JAS
  - 38kWh/JAS is based on M30 logs from Canterbury with large knots
  - Pruned logs likely to require less energy/JAS – e.g. 25kWh/JAS
  - Logs with more heartwood require less energy/JAS

Average Spot Price Trend at Tauranga GXP



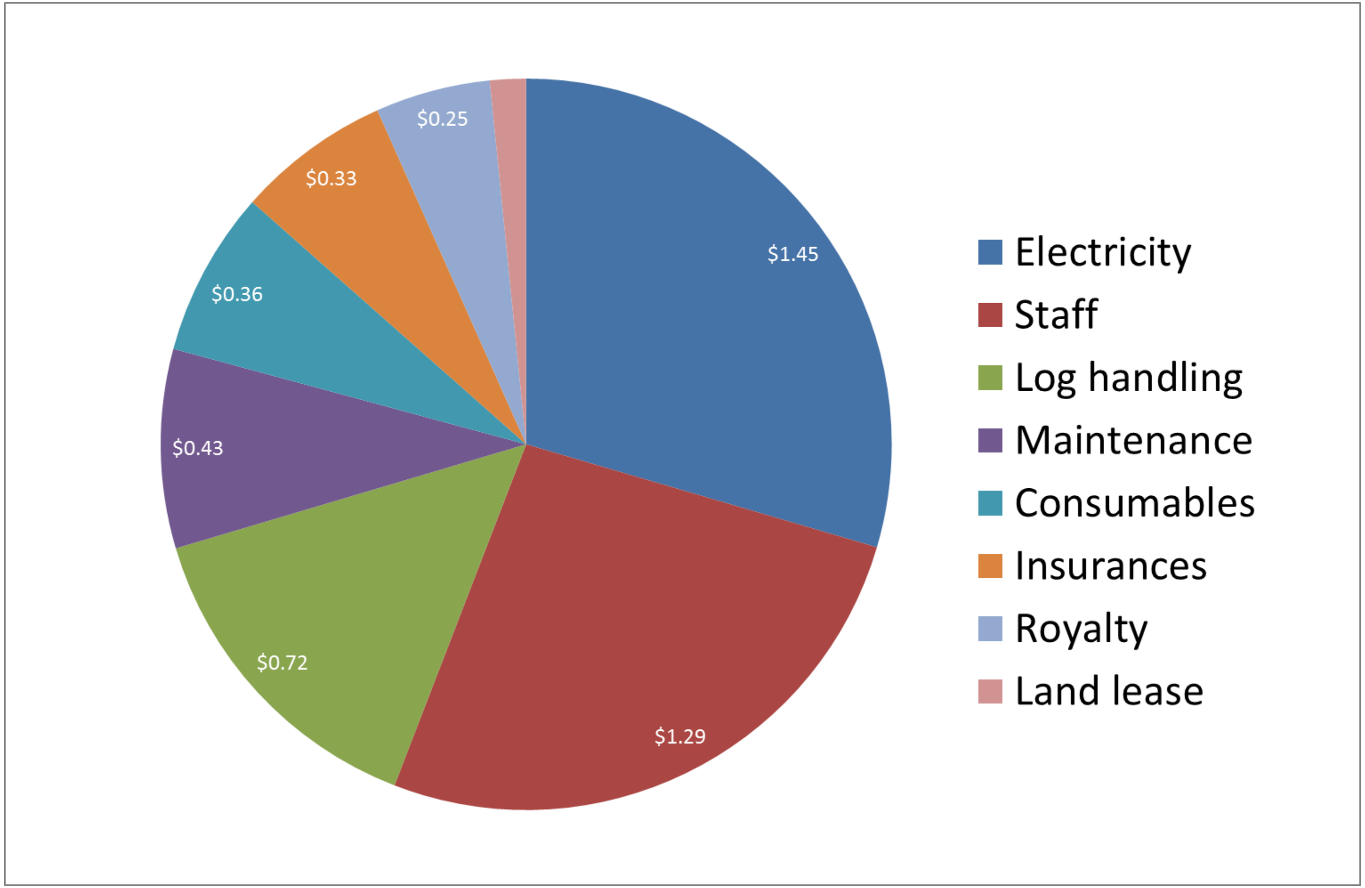
Operating Costs – 38kWh/JAS, 5.5c/kWh



$2.21
$1.29
$0.72
$0.43
$0.36
$0.33
$0.25
$0.08
$5.67/JAS

2016-2017 Spot

Operating Costs – 25kWh/JAS, 5.5c/kWh



$1.45
$1.29
$0.72
$0.43
$0.36
$0.33
$0.25
$0.08
$4.92/JAS

2016-2017 Spot

IP Protection

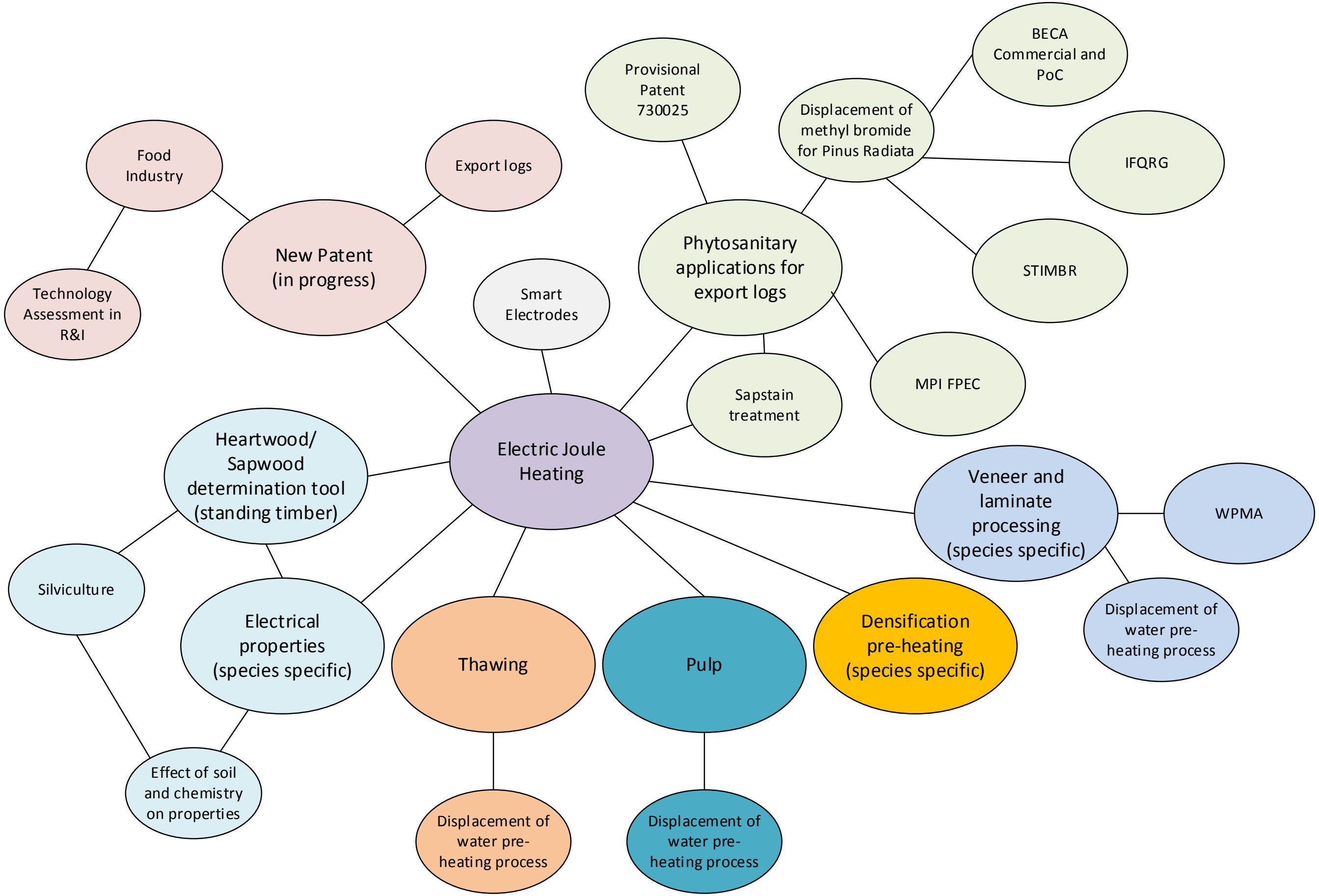
- New Zealand Patent Application 730025
  - Electrode system
  - 1D model-based control system
  - EM shielding system

- Further Patent Application, related to non-uniform heating, in progress

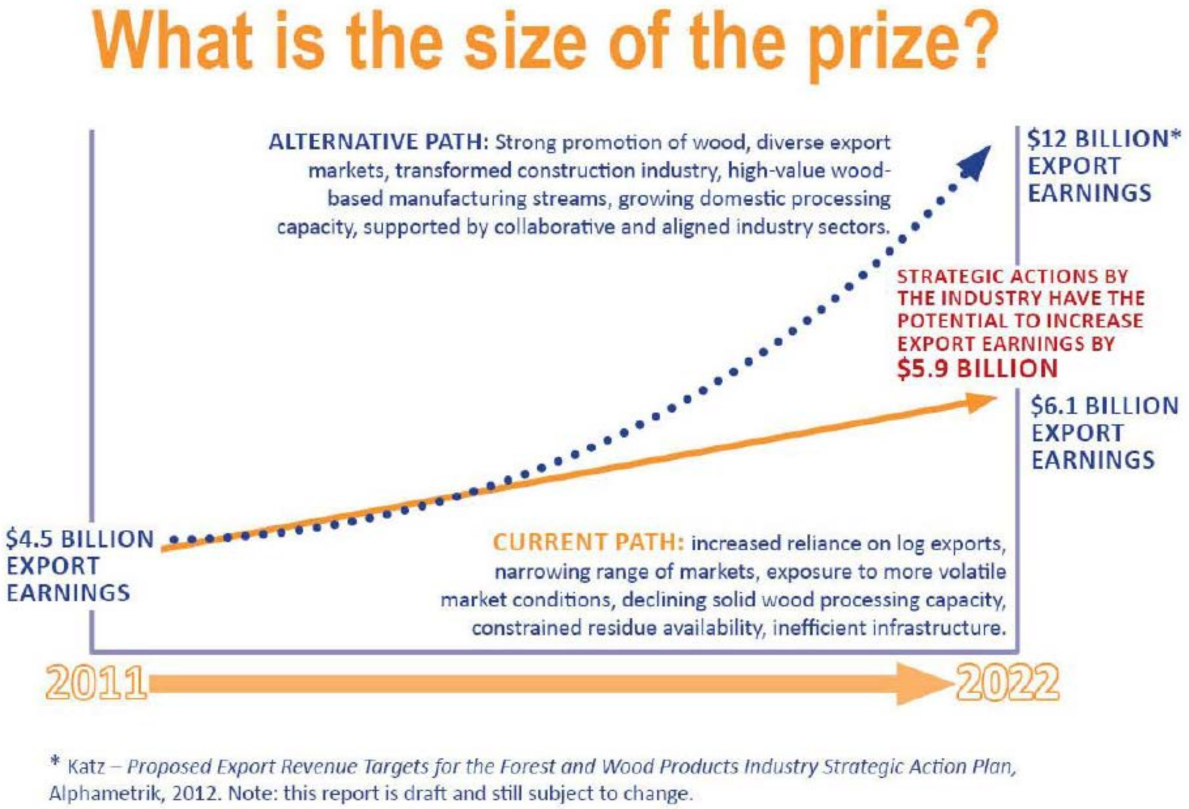
Journal papers in process

- Current distribution measurements in smart electrodes applied to logs undergoing Joule heating
- Practically validated computer modelling of the Joule heating process in *P. radiata* logs
- Electrical conductivity measurements of NZ plantation timber species to enable accurate modelling of Joule heating
- Active EM field cancellation for Joule heating applications
- Analysis of non-uniform Joule heating using experimental and computational approaches

Technology road-map



Woodco – The Woodscape Study



Source: New Zealand Forest and Wood Products Industry Strategic Action Plan, Wood Council of New Zealand, 2012

Woodco – The Woodscape Study

- Carried out by Scion in 2012-2013
- Objective: Grow NZ forest exports from $4.5bn in 2011 to $12bn by 2022
- Achievement to date (year to June 30th):

2011	2012	2013	2014	2015	2016	2017
4.529	4.278	4.484	5.151	4.629	4.845	4.804

- Why zero progress? Because negligible investment?

Source: MPI

Woodco – The Woodscape Study: Findings

- Compete:
  - Increase value of NZ products
  - Increase scale of processing plant
  - Increase productivity through capital investment
- Transform:
  - Use K & A grade logs to make industrial plywood
  - Relocate industrial plywood processing back to NZ
- Innovate:
  - Engineered wood products
  - Fuels & Chemicals

Joule heating funding 2007 - 2017

Year	External Funding	Finance Source
2007	$0	EPECentre
2008	$0	EPECentre
2009	$30K	MAFBNZ
2010	$0	EPECentre
2011	$30K	STIMBR PGP
2012	$0	EPECentre
2013	$250K	MBIE STIMBR Scion
2014	$250K	MBIE STIMBR Scion
2015	$250K	MBIE STIMBR Scion
2016	$250K	MBIE STIMBR Scion
2017	$0	EPECentre

Required funding 2017 onwards

- Maintain research capability: ~ $200 K p.a.
  - Investigate Sapstain destruction
  - Investigate veneer peeling and other processes
  - Investigate other timbers: Douglas fir, durable eucalypts etc.

- Build 1MW prototype production line: ~$5 M over 3 years
  - Dual purpose:
    - Phytosanitation
    - Added value processing

Acknowledgements

- EPECentre and UC ECE staff and postgraduates, especially Nurzhan Nursultanov, Ryan van Herel, Paul Agger, Edsel Villa, David Healy, Joseph Lawrence, Allan Miller and Pat Bodger
- UC CAPE staff, especially Justin Nijdam, Shusheng Pang, Graham Mitchell and Leigh Richardson
- UC Forestry staff, especially Clemens Altaner and Nigel Pink
- UC CNRE staff, especially Alan Poynter
- STIMBR, MBIE and MPI for funding this work
- Scion for their collaboration and support
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Questions?

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