andrew.bissell@sunamp.com
Chief Executive Officer
+44 795 774 8445

Sunamp

Domestic-scale Thermal Storage using Phase Change Materials and Heat Pumps

Sunamp Ltd

- Advanced thermal energy storage
- Founded in 2005 in Edinburgh
- Key materials R&D partnership with University of Edinburgh
- UK R&D and manufacturing
- Products now launched and in serial production
- 38 people directly employed
- First >1500 homes impacted inc:
  - >625 homes in social housing
  - Hundreds of paying customers
- First OEMs signed for Global Markets
- Raised £8M Equity & £5M Grants
- Raising £4.5M Series A now for sales & manufacturing expansion

Summary

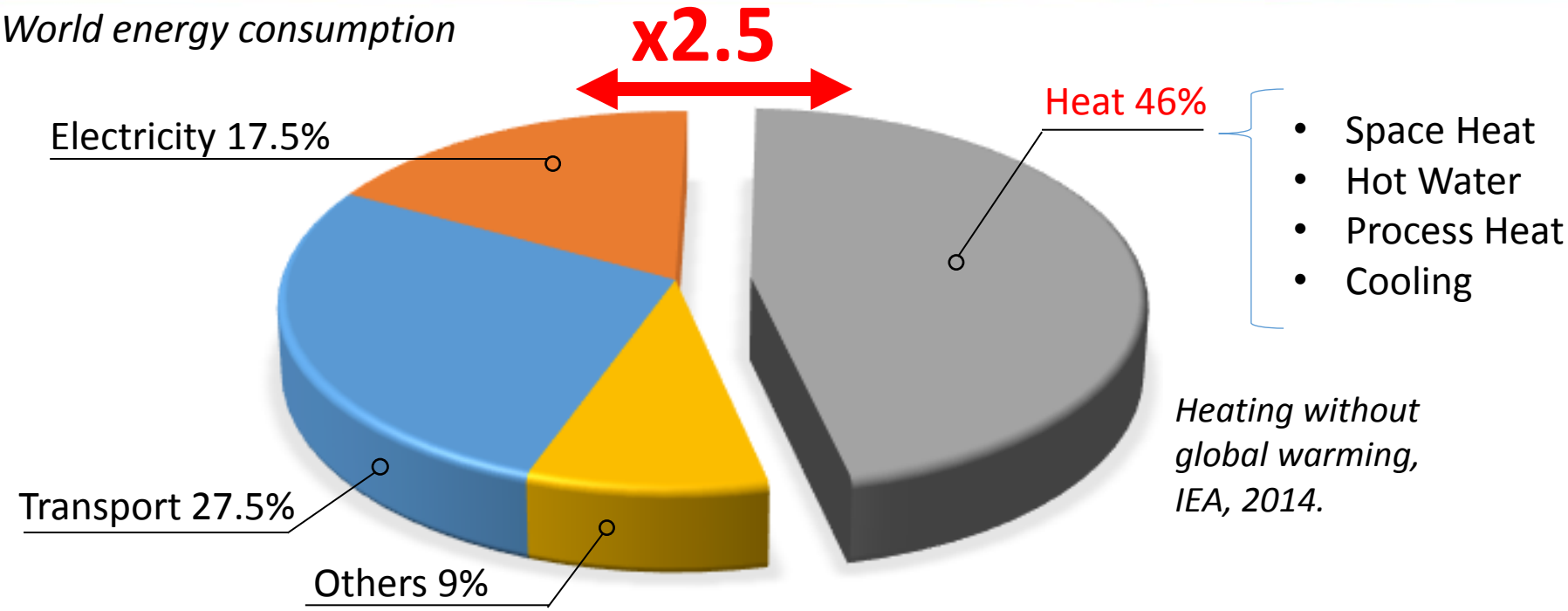
Sunamp

- One-of-a-kind “Heat” Energy Storage play
- Aligned to, and enabler of, key Energy sector trends
- Huge addressable market (both existing & emerging)
- Increasingly compelling product competitiveness
- Seasoned management team & Board
- £7 million fund raise to support commercial ramp

The Heat Opportunity

Sunamp

World energy consumption



- Space Heat
- Hot Water
- Process Heat
- Cooling

Heating without global warming, IEA, 2014.

Electrical storage:

- ✗ Over invested
- ✗ Overcrowded
- ✗ High entry barriers
- ✗ Materials questions

Heat storage:

- ✓ Has not changed in centuries
- ✓ Ripe for improvement
- ✓ More heat storage needed
- ✓ Low cost, sustainable materials

Note: Sunamp can also address (Transport) and interplay with (Electricity) other Energy segments

Source: International Energy Administration

Sunamp Leadership Team

Andrew Bissell

CEO

Sandy Gataora

CTO

Trisha Miller

CFO

Susan Lang-Bissell

COO

Stewart Rowell

CRO (Acting)

Trevor Cross

Head of UK Sales

Bob Austin

Global Automotive Business Manager

Maurizio Zaglio

International Business Development Manager

Bill Edrich

Global Head of Commercial & Industrial

Bob Pettigrew

Chairman

Prof. Colin Pulham

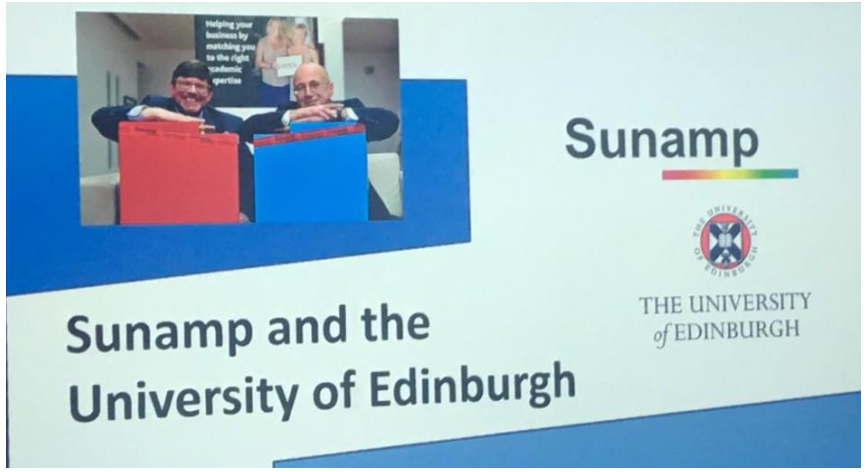
Head of School of Chemistry, University of Edinburgh

Dr David Oliver

Materials Development Manager

Award Winning Academic-Industry Collaboration

Sunamp



Kate Fisher, PhD

David Oliver, PhD

Colin Pulham, Professor, Head of School

Andrew Bissell CEO

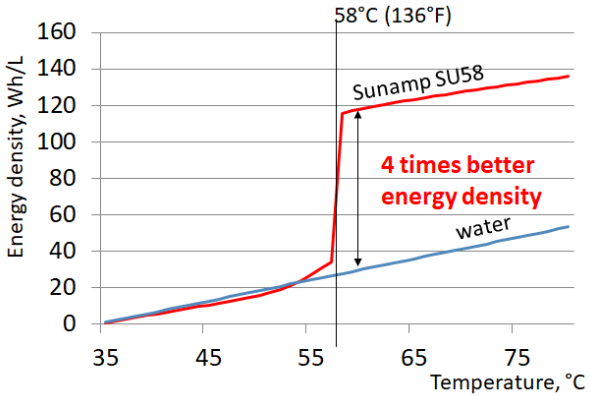
Rowan Clark, PhD

Emily Goddard, PhD Student

Scottish Knowledge Exchange Awards 2019, Powerful Partnerships Award

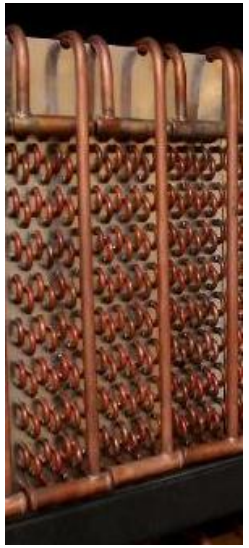
The Sunamp Idea – Heat Battery

Sunamp



High Energy Density

Melting and freezing a PCM (Phase Change Material) stores 3-4 times as much energy in latent heat as the sensible heat of water in a hot water cylinder. **Required** a material breakthrough to stabilize a well-known, non-toxic, low-cost but unstable PCM. **Achieved**



High Power

High power charge and discharge for rapid recovery and high flow rate hot water is key user requirement. But the PCM has very low thermal conductivity. **Required** a mechanical design with high-power, low-cost heat exchanger inside, so heat can be rapidly charged into the PCM in the heat battery and equally quickly extracted. **Achieved**

Energy Efficient

Want very high efficiency, low heat loss (ErP A+). **Required** vacuum insulation panel (possible due to cuboid design). **Achieved**

Scalable, Modular & Stackable

3 kWh to >1 MWh for various applications. **Achieved**

What are phase change materials?

Sunamp

- PCMs utilise the latent heat associated with a phase change

  Liquid → Solid Exothermic

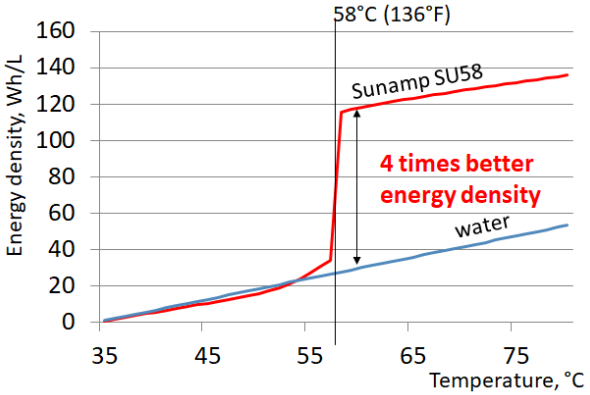
  Solid → Liquid Endothermic

- In 1761, it was Joseph Black that deduced that the application of heat to ice does not cause a rise in temperature of the ice/water mixture, but rather an increase in the amount of water in the mixture:

  "And this very phenomenon is partly the foundation of the opinion I have proposed; for if we examine what happens, we may perceive that a great quantity of heat enters the melting ice, to form the water into which it is changed, and that the length of time necessary for the collection of so much heat from the surrounding bodies, is the reason of the slowness with which the ice is liquefied."

- This led to his discovery of latent heat

Joseph Black



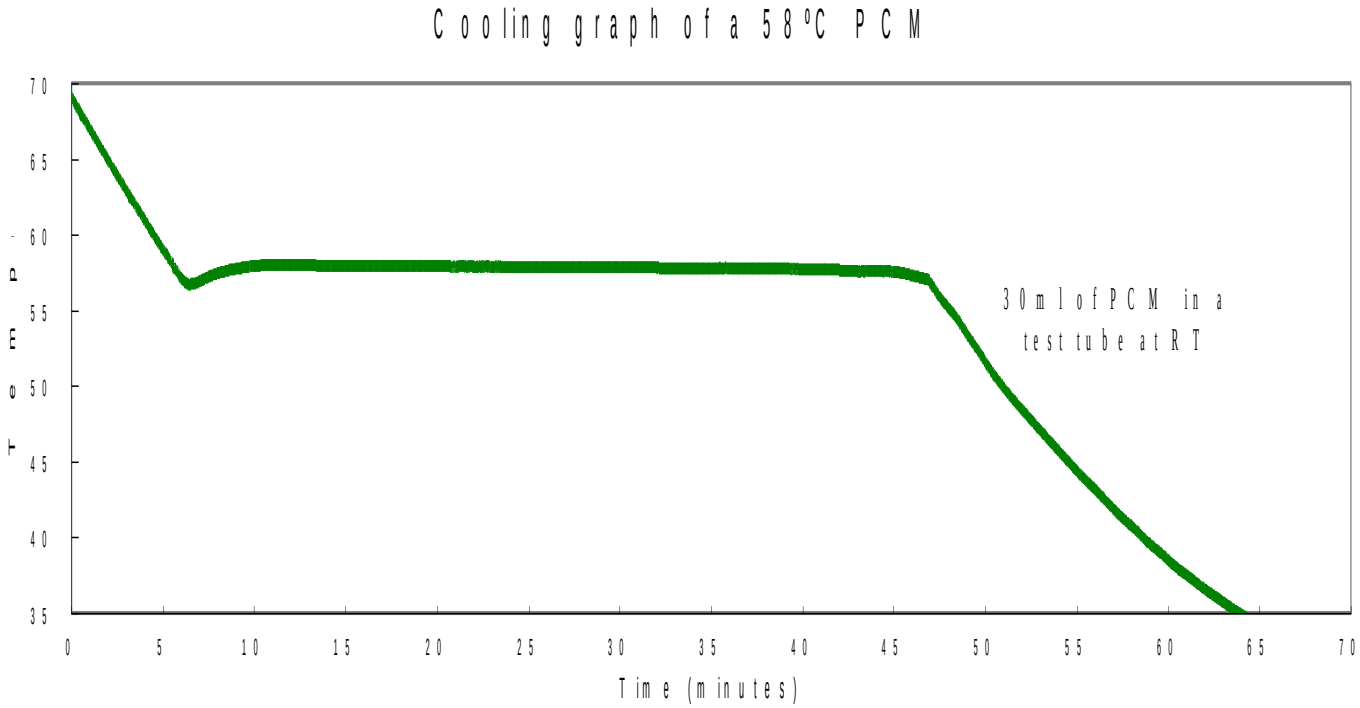
Compounds used as Phase Change Materials

Sunamp

- Organics – potentially very attractive, but low density, flammable
- Salt hydrates - have far superior energy density, but are rarely clean melting or stable over thousands of cycles (>10,000 **required** for heat battery applications), often corrosive and/or toxic

Water	Specific heat of water
ΔH_f = 332 kJ kg^{-3}	4.18 kJ kg^{-1} K^{-1}
0°C	22⟶95°C
306 kJ dm^{-3}	306 kJ dm^{-3}

PCM	Melting point	Latent Heat (kJ kg^{-1})	Latent Heat (kJ dm^{-3})
$CaCl_2/CaBr_2 \cdot 6H_2O$	15°C	120	180
$CaCl_2 \cdot 6H_2O$	29°C	190	285
Tetracosane ($C_{20}H_{42}$)	51°C	255	191
$NaOAc \cdot 3H_2O$	58°C	250	325
$NH_4Al(SO_4)_2 \cdot 12H_2O$	94°C	200	300



Desirable Properties for PCMs include

Sunamp

- Reproducible performance over multiple (1000's) of heating/cooling cycles
- Appropriate temperature range(s)
- Low volume leading to high energy density
- Efficient thermal conductivity
- Long term (i.e. years) chemical stability e.g. with respect to corrosion of construction materials and towards external factors such as variable relative humidity
- Low cost
- Low toxicity and non-flammable

Most PCMs on the market fail some/all of these tests

Essential to map, understand, and control crystallisation processes

Reproducible performance often compromised

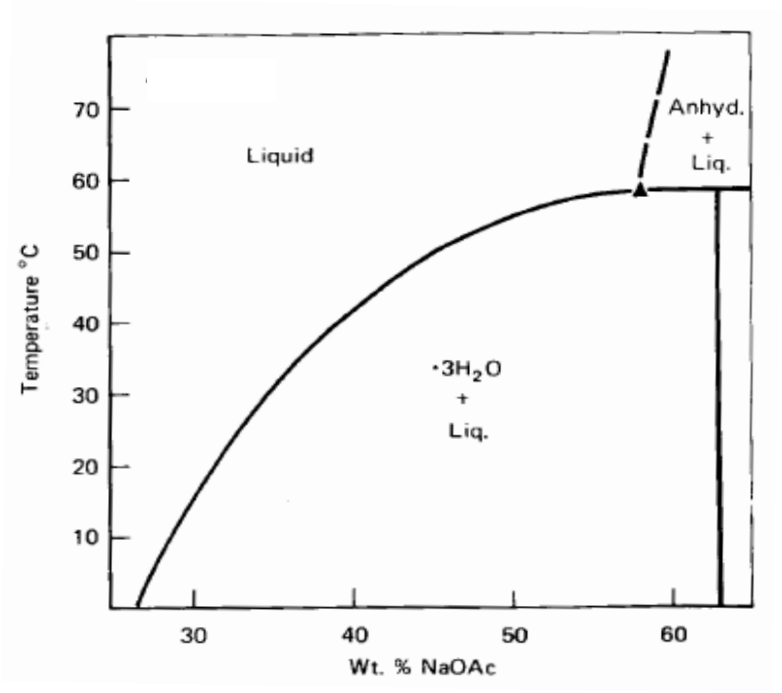
- crystallisation of other phase
  - phase segregation to give anhydrous salts
  - short-lived intermediate phases
- nucleation and crystal growth
  - Need for nucleator to initiate crystallisation
  - Kinetics may be too low for some applications (rate of crystallisation can limit thermal power)

General problems of PCMs

Sunamp

- **Corrosion**
- Low thermal conductivity
- Flammability of low melting organics
- Need to be low cost
- **Incongruent melting**
- Sharp melting/crystallisation point needed

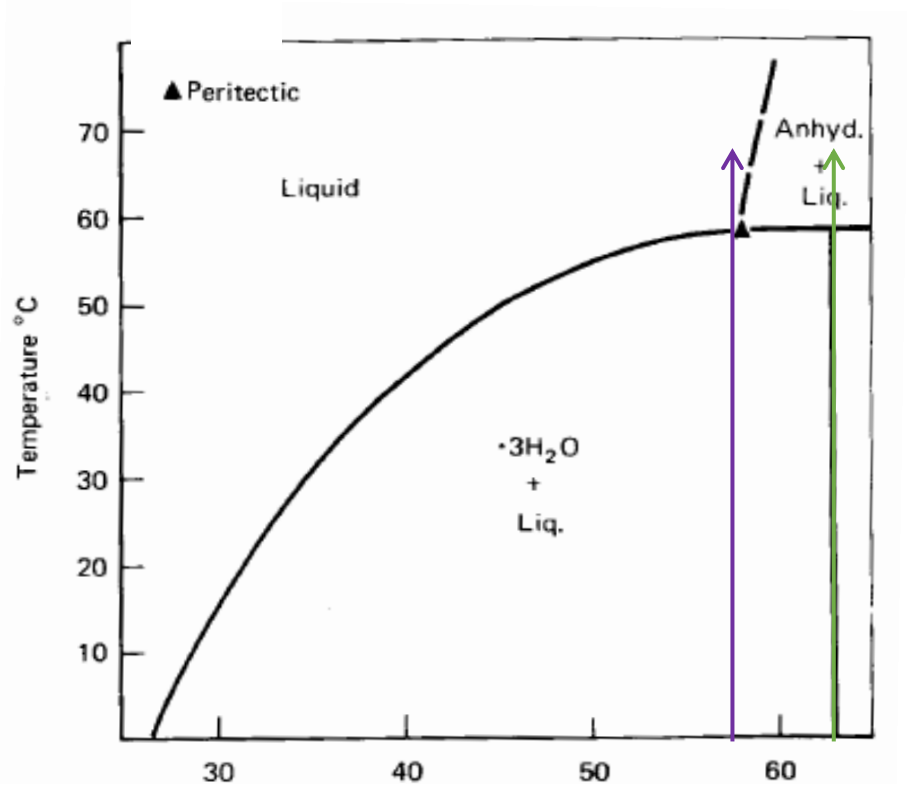
PCM of calcium chloride and magnesium chloride after use in contact with copper heat exchanger

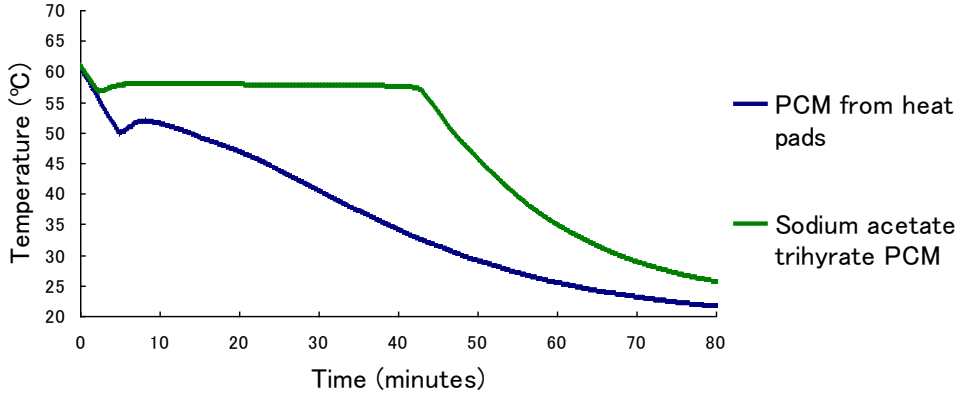


Sodium Acetate Trihydrate

Sunamp

- Sodium Acetetate Trihydrate is attractive in principle:
  - High energy density 325 kJ dm^{-3}
  - Low cost
  - Easy to produce
- Issues - Incongruent melting:
  - When pure sodium acetate trihydrate melts it forms a solution *and* anhydrous NaOAc, thus is 'incongruent melting'
  - The challenge is to have molten $NaOAc{\cdot}3H_2O$ with no anhydrous NaOAc
- Issues - 'simple' extra water technique not fully effective:
  - Extra water (+ 3.92%) can be added so that anhydrous sodium acetate is soluble at 58ºC.
  - But anhydrous sodium acetate will still form without agitation
  - Example: heat pads heat pads are 51.9% water and have a max temperature of 53ºC but tail off quickly
- Prior art around 'polymer' additives as thickeners:
  - Highly viscous polymers have been used to suspend the unwanted anhydrous NaOAc
  - Typically cellulose or starch based polymers have been used
  - Only suspends the NaOAc slowing the inevitable accumulation of this dense precipitate





Crystal Habit Modifier

Sunamp

- University of Edinburgh School of Chemistry breakthrough:
  - David Oliver, PhD student supervised by Professor Colin Pulham
  - EPSRC CASE studentship co-sponsored by Sunamp

- Find a polymer that is soluble in concentrated salt solution

$$Na^+ + {}^-OAc + H_2O \rightleftharpoons Na^+ + {}^-OH + HOAc_{(aq)}$$

- Can be achieved by using selective aqueous alkali-soluble polymers:
  - These suppress the nucleation of NaOAc anhydrous, resulting a homogenous solution when molten
  - No residual NaOAc in the system after extensive testing

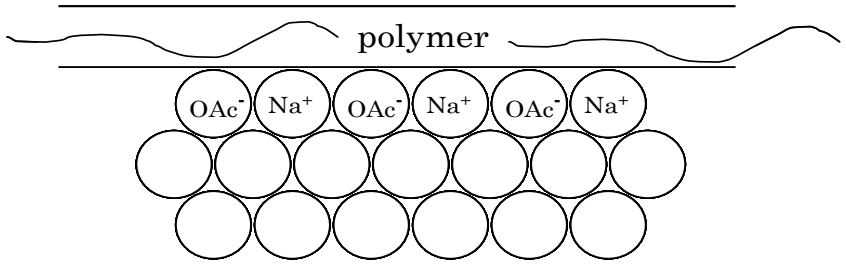
- Big improvement on previous cellulose and starch based polymer

- New method has:
  - Increased workability
  - Optically transparent allowing for simple detection of anhydrous NaOAc
  - Increased storage capacity as NaOAc does not contribute to the phase change energy
  - No degradation

- Sunamp has patents worldwide under IP agreement with UoE
  - Publication delayed while perfecting patents – due to publish soon

Prof. Colin Pulham
Head of School of Chemistry, University of Edinburgh

Dr David Oliver
Materials Development Manager



Possibly via blocking growth of NaOAc clusters

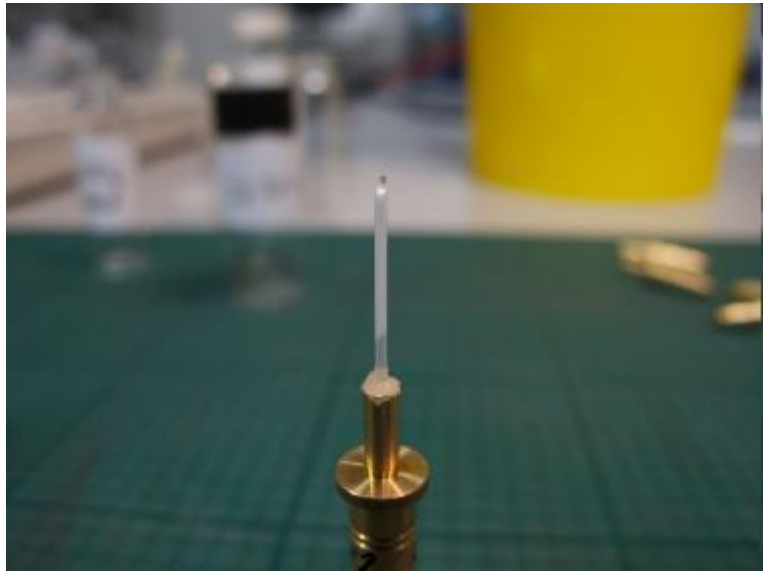
Studied using in situ powder X-ray diffraction

Sunamp

Diamond Light Source, UK

Exploits high flux of synchrotron radiation source and fast detectors

diamond



- Thermal cycling with a new high resolution X-ray crystallogram every 8 seconds
- Identification of active nucleator for $NaOAc{\cdot}3H_2O$
- Thermally induced dehydration is responsible for deactivation of efficacy of nucleation
- No obvious structural relationship between $NaOAc{\cdot}3H_2O$ and nucleating agent
- Confirmation that formulation prevents phase segregation after multiple cycling

SME access to and use of a facility like the Diamond Light Source to study a problem at this intense level would never have happened without a fantastic Academic Collaboration.

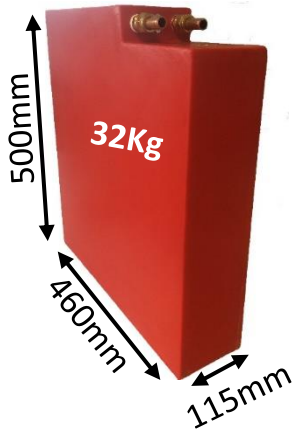
THE UNIVERSITY OF EDINBURGH

Studied using cycle testing

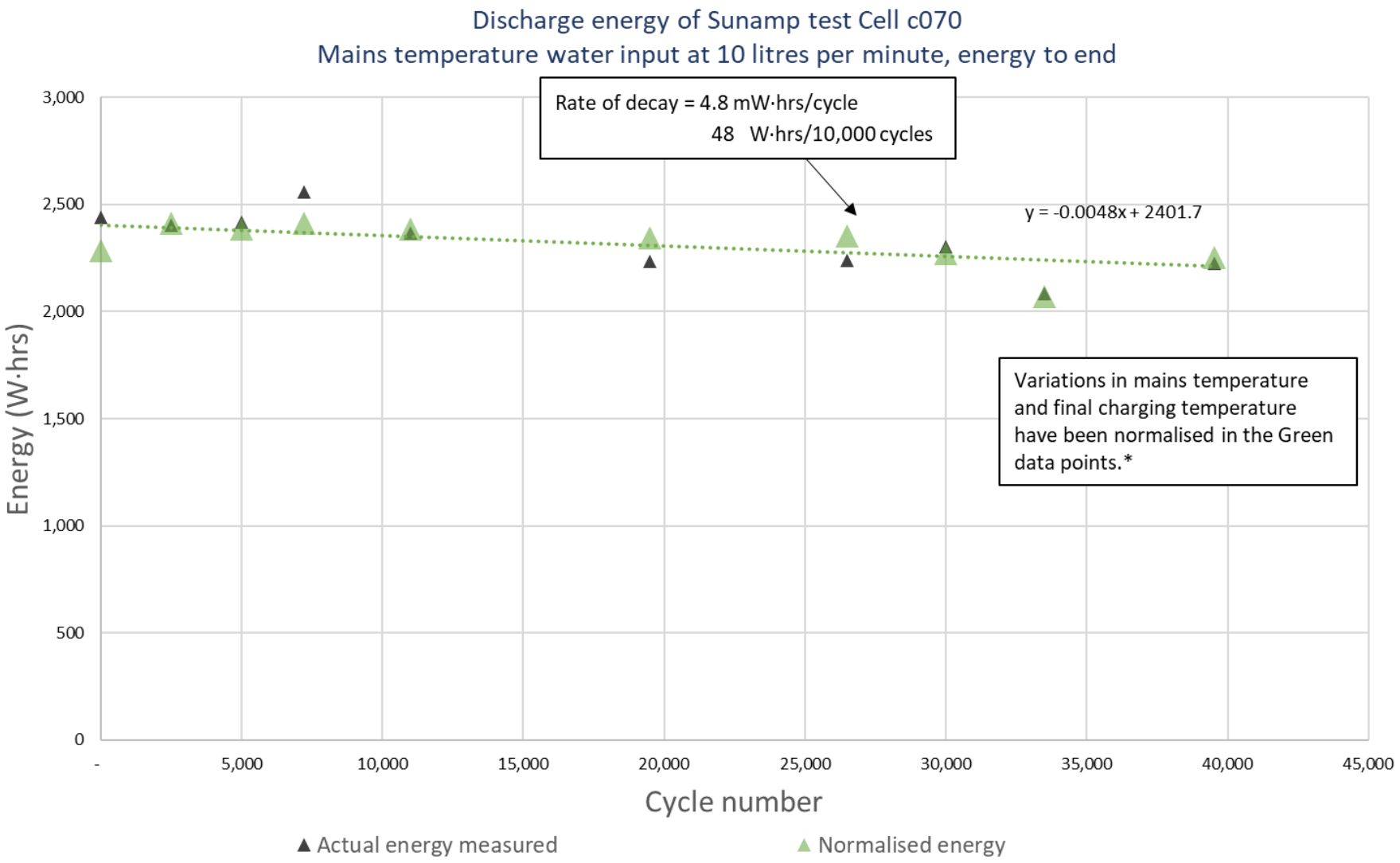
Sunamp

- Cycle is 40 -> 80 -> 40ºC
- Long-term cycle stability established (equivalent to 50+ years residential hot water use)
- >40,000 cycles tested to date on a standard heat battery, randomly chosen from production
- Degradation <10%
- Also proved high thermal power

Sunamp Heat Battery
(Generation 2)



2.25 kWh nominal capacity.



$$* \text{ Energy normalised} = \text{Energy measured (W·hrs)} \cdot \frac{70}{\text{Max output temperature (°C)} - (0.0625 \times \text{Mains temperature (°C)})}$$

Sunamp PCMs are Highly Reliable and Safe

Sunamp

Materials breakthrough to stabilize previously unstable, well-known, non-toxic, low-cost material: Sodium Acetate Trihydrate.

The classic hand-warmer. Useful for outdoor pursuits but unstable and fails in less than 100 cycles.

Commercial PCMs were found to be just as unstable.

Sunamp needed a >10,000 cycles reliability

40,000 cycles achieved with SU58 material developed with University of Edinburgh.

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RAL GÜTEZEICHEN

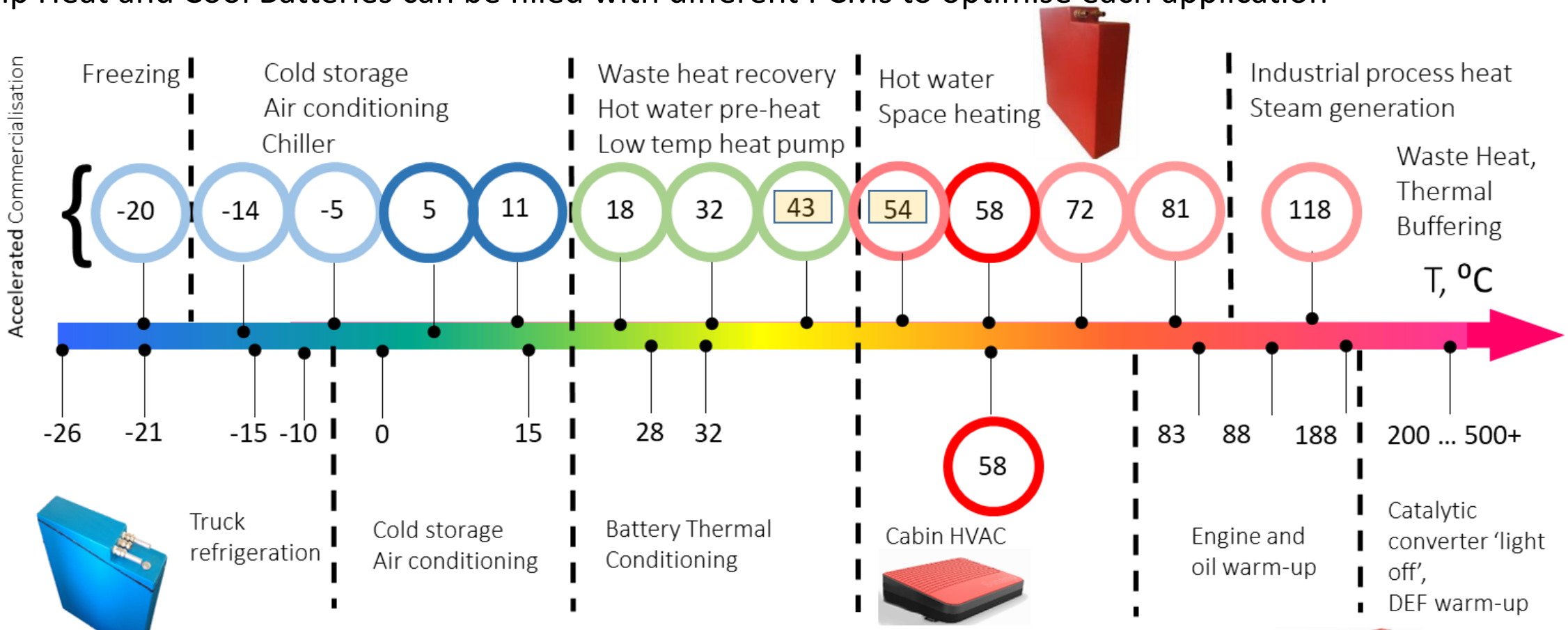
RAL Güte-Gemeinschaft PCM e. V.

Other vendors' PCM issue	Consequence	Solution	Benefit	Comments
Instability via 'phase segregation' Anhydrous fraction drops out	Reducing capacity	R&D with	Now fully stable	Patented formulation
100 cycles before failure	Could not use	Special polymer additive <1%	After 40,000 accelerated cycles over 95% capacity remains	RAL PCM A-grade = 10,000 cycles
Sub-cooling: not solidifying	Loss of useful energy & unreliability	Chemical nucleator <1%	Solidifies on every cycle	Patented formulation
Hand-warmer has to use a clicker to trigger solidification	Complex mechanical control, not OK	Chemical nucleator <1%	Solidification and energy release triggered by flow of coolant/water	
Safety concerns e.g. toxic (Schatz Heat Battery used Barium salt)	Unsafe, so unrealistic to use on a real vehicle	Choose non-toxic salts or organics only	Safe to use, no additional risks, can even be disposed in the environment (see next)	
End-of-life uncertainty	Potential disposal cost Environmental damage	Reformulate to make new PCM	Circular Economy 'Waste' is raw material	Proven process

Flexible Temperatures

Sunamp

Sunamp Heat and Cool Batteries can be filled with different PCMs to optimise each application



Sunamp PCMs are internally developed, and generally inorganic, non-flammable materials. Values indicate phase change temperature. Operating temperature range typically 40 ... >100 °C (90 ... >200 °F) around phase change temperature - consult Sunamp.

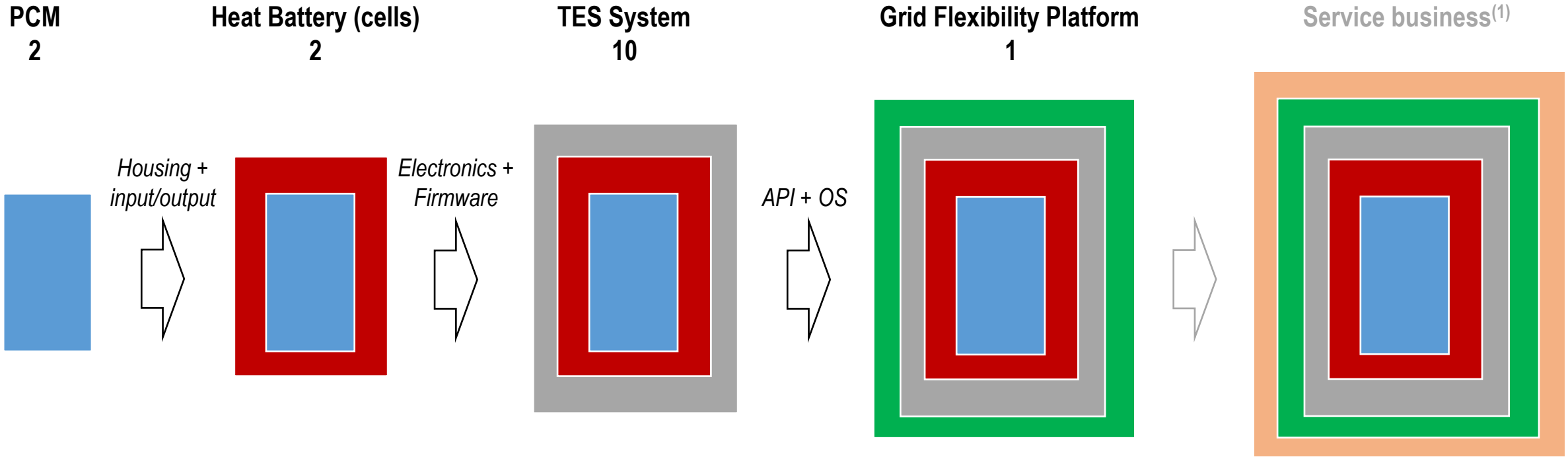
Current commercial products (Space Heat & Hot Water)

Near-term introduction (2019)

Note: PCMs at different level of development and not all commercially available today

System / IP Layers

Sunamp



- Sunamp has ~100 patents pending or granted (~35)
- Significant further grants are imminent
- 15 major patent families (including divisionals)
- Further patents being filed on new PCMs, new types of heat battery and new applications
- Coverage already granted in 19 major countries (e.g. China, Japan, Korea, EU, Russia, Australia)
- Expected to grant in a further 10 countries (e.g. US, Canada, Chile, Mexico, India, Qatar, Saudi Arabia)
- Progressing in all major patent systems (e.g. PCT, US Patent Office, European Patent Office and Asia)
- Invested £900k to date (excluding the R&D costs)
- Building competitive advantage, protection from competition, licenses to OEMs and fundamental exit value

Note: TES = thermal energy storage

1) Possible (currently unfunded) business models

From material to system – in production Today

Sunamp

High Energy Density

Retains PCM compactness when scaling to heat battery size (non-trivial).

High Power

High power heat exchanger inside, so heat can be rapidly charged into the heat battery and equally quickly extracted – high rate discharge.

This means can deliver 20+ litres per minute hot water for showers

This means can rapidly warm a heating system (comfort & energy efficiency points)

Modular

Cuboid and able to stack like Lego®

Cost-Effective

Comparable price to Hot Water Tanks
Lower Total Cost of Ownership
Much lower cost than electric batteries

Modular
14 kWh
75 kW
PCM 58°C
5-80°C
150 Wh/L

SunampPV: Gen2 - Hot Water from PV

Sunamp

Consumer unit

DC/AC inverter

Excess electrical production diverted and stored as heat

Lighting & Appliances

Cold water supply

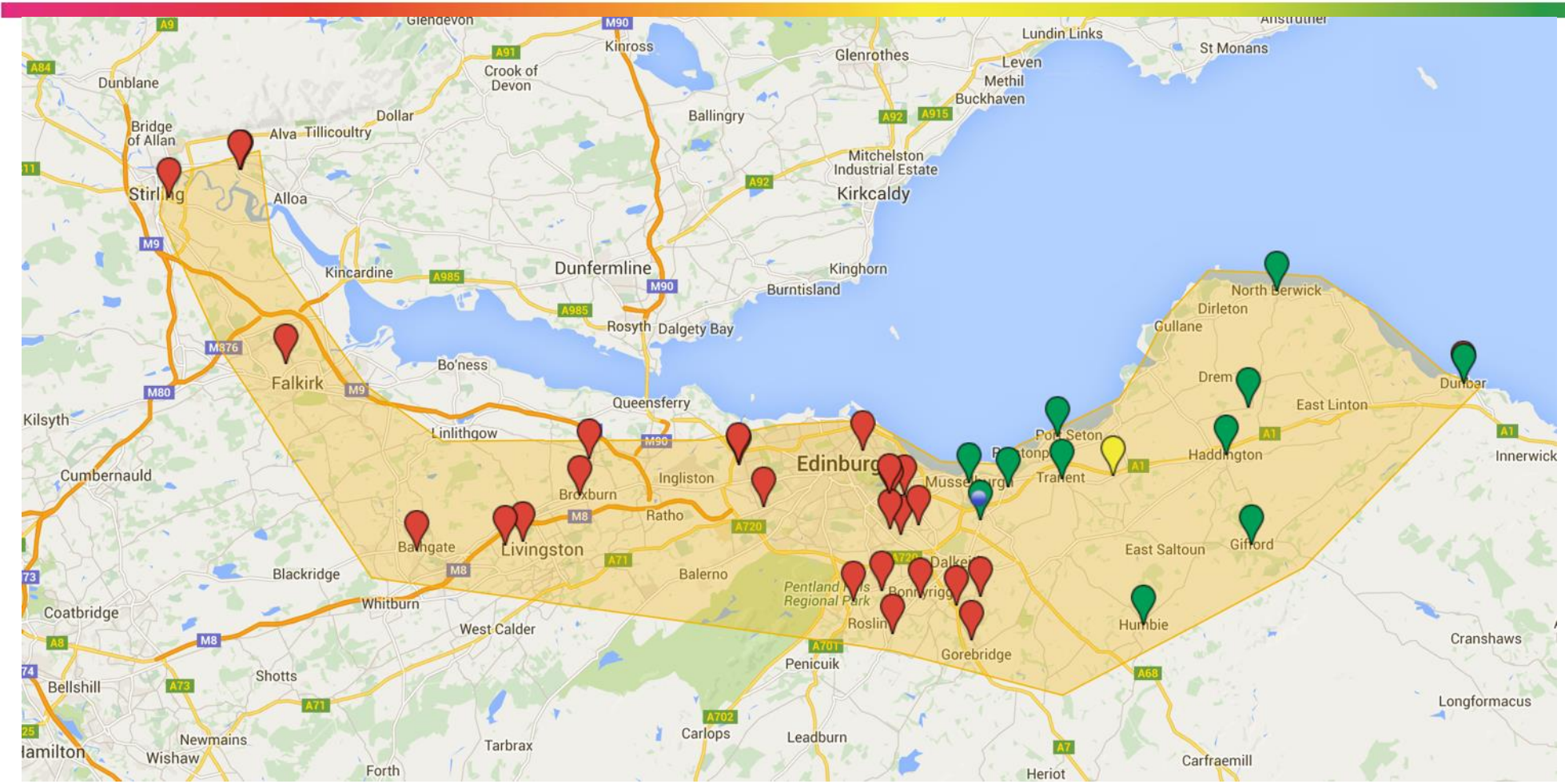
When temperature is below a set point, it is diverted to combi boiler as pre-heated feed

- Enhanced behind-the-meter utilisation of on-site PV.
- Unique link between PV and combi boiler
- Side-steps feed-in tariff or net-metering complexities.
- Flexible: Can also be a primary hot water supply
- Displaces fossil-fuels (gas, oil, propane, LPG)
- Subsequently tested in >400 homes in EastHeat trial

Early adopter testing at Colin Pulham's house!

Validated by Large-Scale Trial (2016 to-date)

Sunamp



EastHeat

Fuel Poverty Reduction: Heat Storage Innovation

Local Energy Challenge Fund (LECF) Phase 2, ref GCF056

elha.com east lothian housing association

CASTLE ROCK EDINVAR HOUSING ASSOCIATION

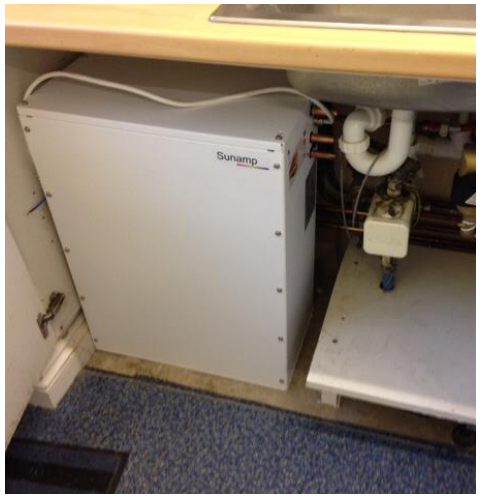
Sunamp

LOCAL ENERGY SCOTLAND

- Over 1,000 tenants positively impacted with 20%+ bill and energy savings
- 766 Gen-2 Heat Battery Products installed (retrofit) in over 600 homes by 1Q 2016
- In daily service for 2 years with high reliability providing heat and/or hot water to circa 2,000 people
- 4.6 MWh total storage in 2,042 Heat Battery 'Red Cells'

400+ Sunamp PV with solar PV and Combis

Solar PV, combi boilers and Sunamp Storage



- Electricity consumption reduced due to PV on roof — £101 SAVED
- Gas consumption reduced as a result of SunampPV — £74 SAVED

The Lynne Family

"Our hot water is plentiful, comes out of the taps quickly and is an excellent temperature"

Alec & Joan

"In comparison to the old system, the new system performs to a much higher standard, providing a larger quantity of hot water for a much cheaper price."

John and Jayne

"It gets a bit to getting used to, switching on the hot tap normally you would hear the sound of the gas boiler that doesn't happen any more"

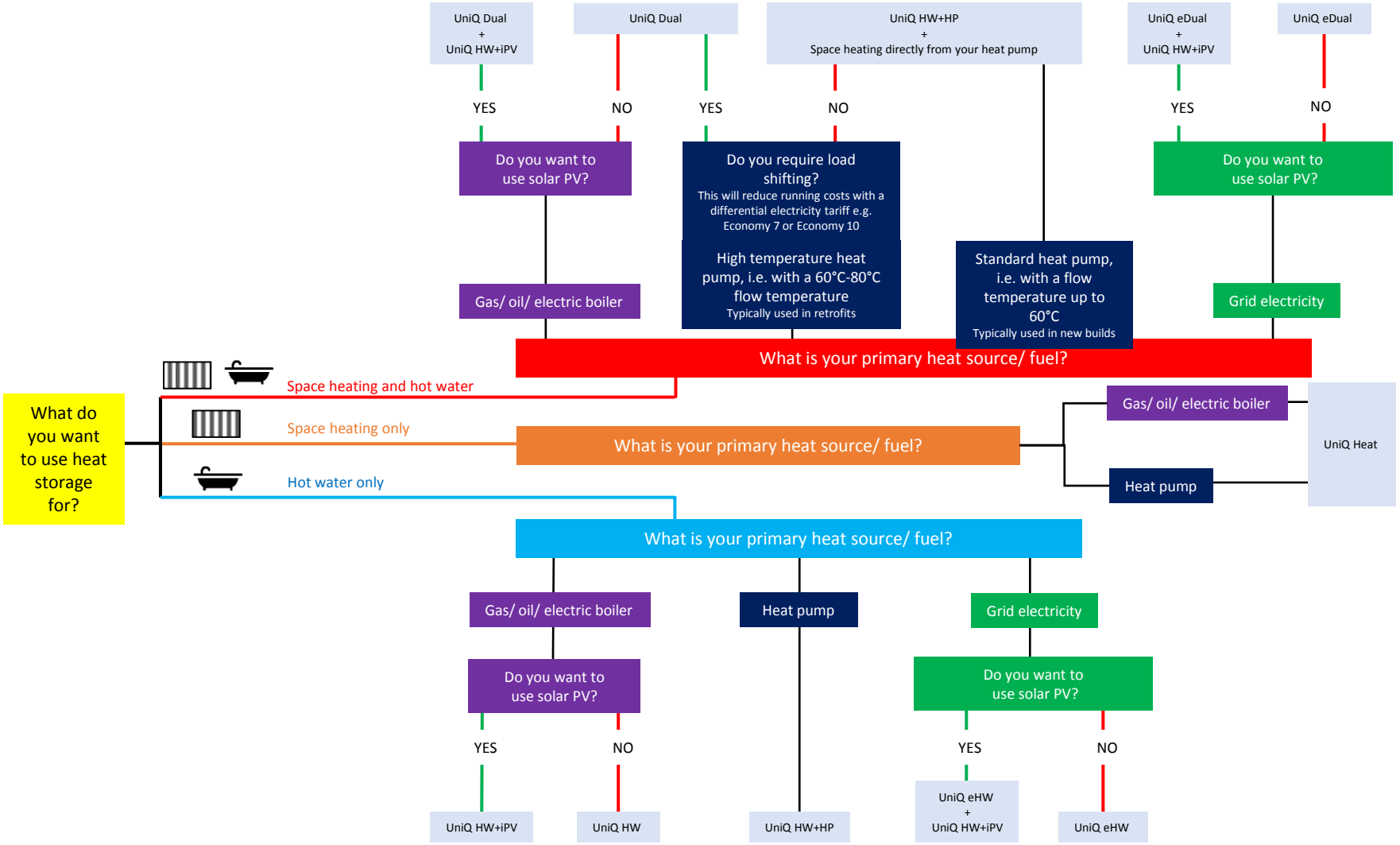
The future of energy storage is…..

Sunamp

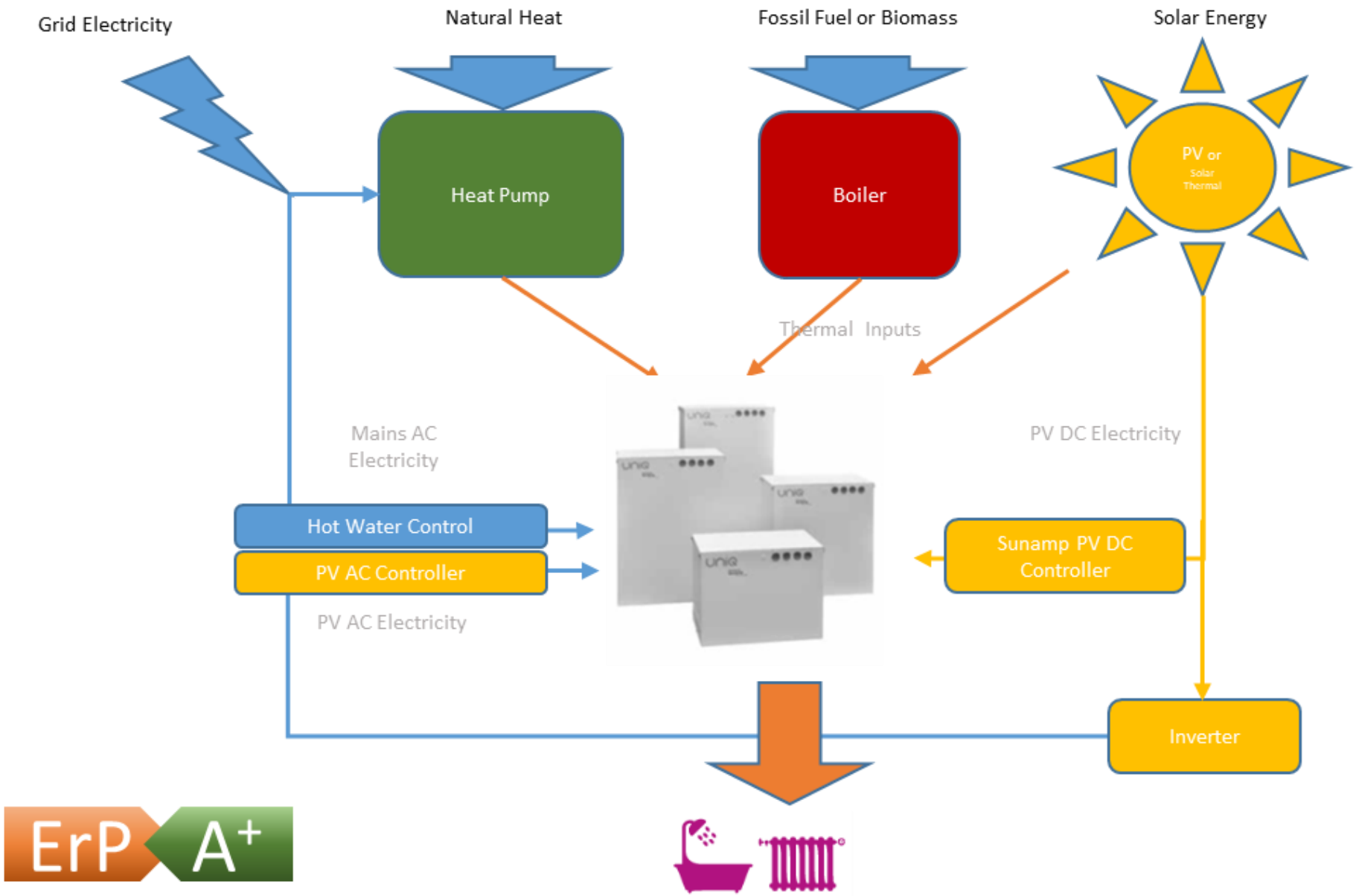
uniQ®

Introducing Sunamp’s Generation 3 Heat Batteries

Flexible Applications



Flexible Applications



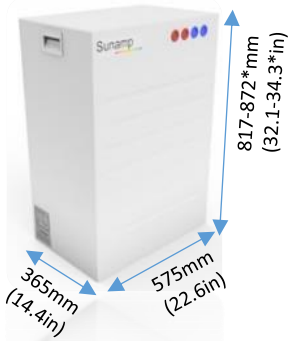
Product Line

Most commonly sold size.
Replaces 210L water tank.

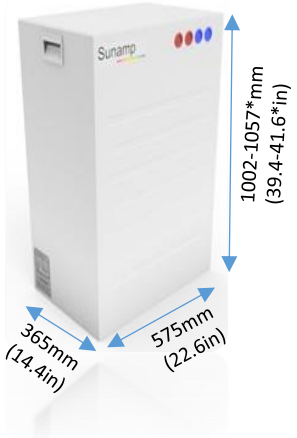
UniQ 3

UniQ 6

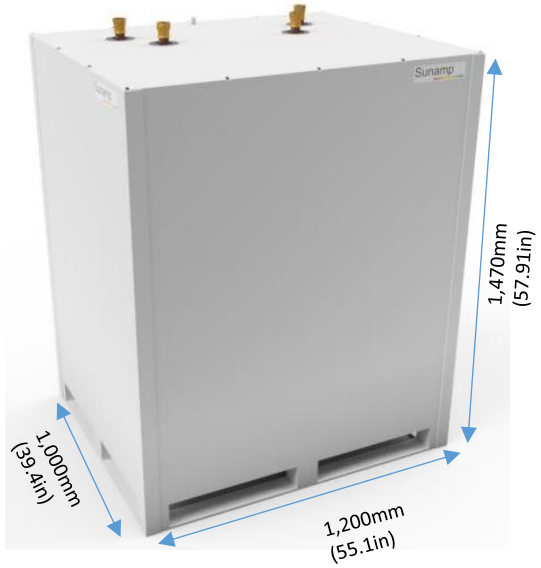
UniQ 9



UniQ 12



UniQ 80



*height for models including stand-by electric heaters

Key benefit:

- Extremely low heat loss
- Highest efficiency on the market
- Nearest competitor at 201L capacity is water tank with B rating

ErP A+

Other benefits:

- Minimised pipework
- Lower installation cost
- Space saving (70%)
- Price similar to water storage

Model Example	Measured kWh	Equivalent cylinder (L)	Heat Loss (kWh/24h)	Comments	ErP Rating
UniQ HW 3	3.5	70	0.449		A+
UniQ Heat 6	7	140	0.649	Stackable two high	A+
UniQ HW 9	10.5	210	0.738	for larger storage	A+
UniQ Dual 12	14	280	0.809		A+
UniQ Heat 80	90	1800	2.2 (provisional)	Palletised, 1.5 Tonnes	Non ErP

Published Worldwide PCT Applications:
WO 2009/138771, WO 2011/058383, WO 2014/202974,
WO 2014/195691, WO 2014/191778, WO 2015/025175, WO 2017/221025

Compact

Low heat loss

Albin Trotter ATI E-305L

-71% in volume

Equal energy stored

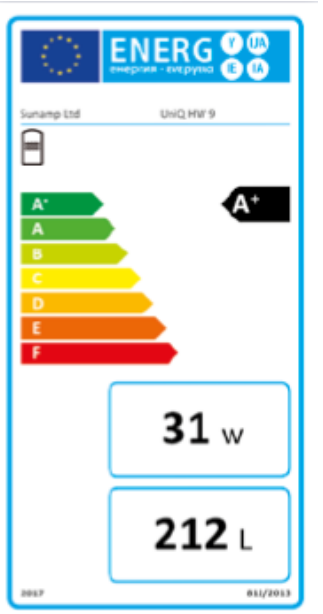
→ ½ →

½ in both height and depth

→ ½ →

UniQ eHW 12

Cylinder (210L/equiv)	Heat loss/24h	Annual
Installed base (10 years old)	2.5 to 3.5 kWh	1,095 kWh
Brand new, top quality	1.3 kWh	475 kWh
Sunamp UniQ HW 9	0.74 kWh	270 kWh



Product Usage

Better than unvented hot water cylinder.

Benefits:

- Mains pressure hot water
- Rapid reheat
- High discharge flow rate
- Compact Size
- Low heat losses, ERP A+
- No Pressure & Temperature safety valve
- No risk of explosion
- No discharge pipework
- Flexible Siting, lower cost install
- No need to comply with G3 regs
- Lower skill plumber can install
- No official maintenance requirements
- No legionella risk
- Modular & flexible
- Multiple charging methods

1500 Installations of Products Completed

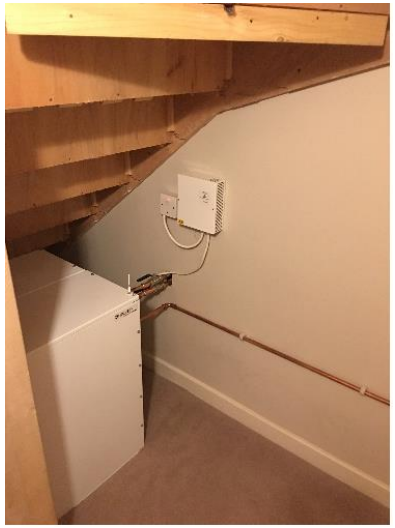
Sunamp

Small district heating with Heat Battery

150 electric hot water tanks replaced by Heat Battery

Village Hall with PV, 2x heat pumps and PV

Our customers innovating new siting locations



In a prestige Passivhaus project as seen on Grand Designs

Long Trial Heat Battery + ASHP (2013 to-date)

Sunamp

Department of Energy & Climate Change

bha Thriving Communities

- Trial in 7 homes funded by DECC – all still running, with measured bill savings 45-60%
- In service for 6 winters (some still with Gen-1 heat batteries, some upgraded to Gen-2 or Gen-3)
- Off-peak 'Economy 10' or 'Economy 2000' electricity (10 or 20 hours per day off-peak)
- Combined w/ Air Source Heat Pump's Coefficient of Performance (Seasonal CoP ~2.2 measured)
- Heat Battery storage provides time-shift: run heat pump when cheap, use heat at any time
- Easy retrofit installation – about to start 145 with a Scottish rural Housing Association using UniQ

High Temperature Heat Pump

Spec
40 kWh Sunamp heat battery
Air Source Heat Pump (Daikin)
Works to -25ºC ambient

SunampStack

Central Heating

Hot Water

ASHP Heat Battery Trial Results

Sunamp

Department of Energy & Climate Change

bha Thriving Communities

Results and Benefits:

- typical running costs savings range from 45% to 57% (using 2013 prices)
- carbon emission reductions range from 17% to 36% (using 2013 emission factors, since then grid carbon ~halved)
- Replicated at ONGO homes in 2016/2017, installing in old coal cellars + many private customers

CASE A – From Electric Heat and Water

This is a 2-bedroomed house with 2 working occupants. They are heavy hot water users having 2 deep baths in the morning and 2 deep baths in the evenings

Annual Savings on Heat and Hot Water		
kWh saving	Bill saving	CO_2 Saving
59%	56%	29.1%
8,404 KWh	£602.17	1259 $KgCO_2$

CASE B – From ETS and Electric Hot Water

This is a 3 bedroomed house lived in by a young working couple, their heat and hot water usage is normal. This household had night storage heater. Comfort has improved.

Annual Savings on Heat and Hot Water		
kWh saving	Bill saving	CO_2 Saving
40%	45%	36%
4,921KWh	£414.78	1596 $KgCO_2$

CASE C – From Electric Heat and Water

This is a one-bedroom house, semi detached bungalow. The occupier is an retired man who looks after his grandchildren in the early evening so the house must be warm - Achieved

Annual Savings on Heat and Hot Water		
kWh saving	Bill saving	CO_2 Saving
49%	57%	Not Available
3,291 KWh	£325.91	Not Available

CASE D – From Gas Heating & Hot Water

This is a 5-bedroomed house with 2 working occupants, 1 teenager and 1 visiting young adult. Previously mains gas heated

Annual Savings on Heat and Hot Water		
kWh saving	Bill saving	CO_2 Saving
77%	50%	46%
28,476 KWh	£926.77	3645 $KgCO_2$

Commercial Retrofit – Village Hall

Brief was to remove gas – They wanted to be the greenest village hall

Installation

- 12kWp Solar PV Array was already installed
- We retrofitted 2 Daikin Heat Pumps & 1 Stack
- Removed gas boiler
- Replaced the old inefficient radiators
- Have now added EV Charging for community

Savings and Payback

- The committee have been monitoring their savings and estimate they will save over £3000 PA which is over 50% of their fuel costs
- Payback in 10 years
- Have not switched to off peak tariff yet, which could increase savings

Benefits

- Very easy to control & sets back automatically
- Can heat the 2000 Sq Ft room very quickly
- Radiators replaced with no redecoration required
- Better water pressure

150 Electric Hot Water Cylinder Replacements

Sunamp

Linstone HA

Occupant Benefit

- Savings of £51 PA, single occupancy
- Increased comfort, higher pressure
- Increased space in cylinder cupboard

Owner Benefit

- Annual HW cylinder inspection avoided, no G3 regulation, no P&T pipework required
- Legionella risk and treatment avoided
- Sunamp expected to last 20 plus years
- Reduced maintenance

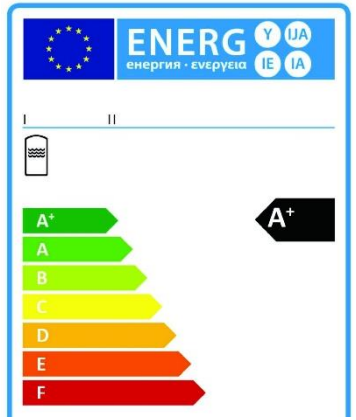
Tenant Comments

"Water pressure is unbelievably brilliant. Not noisy, More space freed up in the cupboard. Pressure has vastly improved things, notably in the kitchen sink, previously I could start the water running walk away and come back to it, now I get the hot water instantly which is great"

Sunamp Highlights

Sunamp

- Sunamp **Heat Batteries** are the world's most energy efficient Thermal Stores
  - Disruptive to hot water tanks (~43m of 107m water heaters sold/year globally, ~$50Bn market)
  - Performance superiority (compactness, energy density, efficiency, flow rate, power, reliability, safety, weight)
  - Cost parity today versus hot water; significant cost advantage by end 2019
  - Complementary to HVAC equipment, electric batteries, renewable energy & intermittent grids
  - Unique applications in high temperature, cooling and automotive



- 36 patents granted, 62 pending – materials, heat battery, system, applications
- Proven via 5 years use in buildings; >1500 systems installed using >4000 heat batteries; very reliable
- Sunamp Factory started production of 3rd Generation Heat Batteries
  - 50x more capital efficient than Tesla-Panasonic per GWh/year production capacity
- Equity of £3m invested to Sunamp Ltd during 2018; £4.5m Series A planned 2019

Sunamp

Thank you

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