Clean Heat in Textile Manufacturing: Aii Lessons on Steam Heat Pumps to Date - July 2026

Executive Summary

In 2025, Aii's Low Carbon Thermal Roadmap identified steam-generating heat pumps as the most promising pathway to cost and emissions reductions in the textile sector — with commercial viability projected from 2030 across India, China, Vietnam, Bangladesh, and Indonesia. This white paper documents what we have learned in the year since that finding, and what needs to happen before 2030 for that potential to be realized.

The most commercially mature steam heat pumps currently deliver around 120°C. That is sufficient for a meaningful share of textile processes - drying, printing, some dyeing - but falls short of the higher-temperature demands of many dyeing processes, stenter heat setting, and specialty finishing. Vendors offering 150°C+ systems exist, but global installations in all sectors remain limited. Until we have proven, stable performance data at those temperatures, broad adoption will remain out of reach.

Heat pumps are not plug-and-play; they require custom engineering, deep knowledge of site-specific waste heat profiles, and integration expertise that most vendors are only beginning to develop. Poor system design leads to oversized equipment, underperforming assets, and damaged confidence in the technology.

The economics compound the challenge. Across 17 textile manufacturers screened in India, China, and Vietnam, the average electricity-to-fuel price ratio was 4.02, far above the threshold for an unassisted business case. Combined with transformer capacity limits, 5–8 year payback periods, and a supplier base accustomed to a 2- to 3-year ROI approval, the commercial gap is significant. Grant funding and brand-backed financing are not optional extras; they are currently a necessity.

Equally important is what we call the partial electrification reality. With commercial steam heat pumps capped at around 2 MW and average boiler sizes

in our survey at nearly 18 MW, full electrification of a typical textile facility is not a near-term prospect. Meaningful decarbonization in this decade will come from targeted, process-specific installations, not whole-boiler or whole-facility transformation.

This makes steam optimization and de-steaming a strategic priority, not a secondary workstream. Factories that reduce their steam load and lower required temperatures create the conditions in which heat pumps perform best: smaller systems, better Coefficient of Performance (COPs), shorter paybacks. Aii is treating steam optimization and de-steaming as preparation for electrification.

What we believe needs to happen by 2030 for commercially mature 150°C steam heat pump systems is an increase in vendor engineering capability; a growing base of installed cases; and sustained brand support to close the financial gap for early adopters. The gap between what is theoretically possible and what is deployable today is significant, and it is not closing on its own.

Aii's role is to accelerate this work through feasibility studies, grant-funded pilots, technical assistance, and industry alignment. This paper is part of that work.

Aii Heat Pump White Paper

Overview of Aii’s work on heat pumps

Since the launch of the roadmap, Aii has partnered with engineering firms to conduct feasibility assessments on hot water heat pumps and provided grants to textile manufacturers installing both hot water and steam-generating heat pumps. Hot water heat pumps produce low- to medium-temperature water, typically up to 70–90°C, and are well suited to processes such as washing, rinsing, and dyeing where large volumes of heated water are required. Steam-generating heat pumps, by contrast, produce pressurised steam at temperatures generally above 100°C, making them appropriate for more energy-intensive textile processes such as drying, fixation, and finishing that require either direct steam injection or high-temperature indirect heating. Both technologies replace fossil fuel-fired boilers as the heat source, but address different points in a mill's thermal energy system.

We've learned that while hot water heat pumps are a simpler technology than steam generation, this does not necessarily mean they are easier to implement. There are still very few case studies of their use in the textile sector, despite the technology's maturity. Our feasibility studies in India are showing that there are still technological barriers to implementation, as textile manufacturers have yet to see and learn from installed cases, despite good paybacks, some even less than two years. Our hot water heat pump pilot is an ongoing project, and we are looking forward to translating the proposals into implementation. Formal insights will be published later this year as this project continues in Italy and Türkiye.

Since steam-generating heat pumps have even fewer installed cases and present actual technical challenges and high paybacks, we have focused our Climate Solutions Portfolio grants on supporting installations of the technology to drive sector-wide learning. We have awarded grants to two projects (Bangjie Knitting Vietnam & Jiangsu Lugang Science & Technology) that will install heat pump systems designed to deliver up to 143°C. This year, we also launched a feasibility assessment project for steam heat pumps across India, Vietnam, and China. While these projects only recently began, the textile manufacturer engagement and screening process has already provided us with invaluable insights, shared below.

Steam heat pump temperature limits vs textile process needs

In a **closed-loop** system, a dedicated refrigerant circulates within a sealed cycle. This offers greater flexibility, as it can recover heat from a wide range of sources — hot water, wastewater, cooling systems, or other low-grade waste heat streams — and typically upgrade temperatures to around 90°C.

In an **open-loop** system, the process vapor itself acts as the working fluid: it is compressed and reused directly. This enables higher output temperatures (typically up to 180°C), but is limited to processes that already generate steam or vapor, and the achievable temperature lift is generally less than 30°C.

From our engagement with steam heat pump vendors, we see there is a significant gap between what vendors in Asia can deliver and the temperature range that textile manufacturers in the region require. Today, the most commercially mature industrial steam heat pumps can deliver steam at around 120°C in a closed-loop system. While some systems can achieve 150°C through cascade compression and hybrid configurations in an open-loop system, 150°C closed-loop steam heat pumps have not yet reached the same level of commercial maturity, reliability, and deployment scale. In the sector, the highest temperature we've seen installed is in China: 120°C closed-loop and 150°C open-loop.

Technical note: Heat pumps upgrade low-temperature heat to a higher level using the evaporation and condensation of a working fluid.

For a heat pump to work optimally, there has to be sufficient waste heat to partially power the heat pump, and electricity to power the compressors to lift that waste heat to the temperature needed. This temperature lift represents the technical challenge of heat pumps: The higher the required lift, the harder the compressor must work, which increases electricity use. This also impacts the project's coefficient of performance (COP), which determines the economic viability of the technology.

In the table below, we compare textile process requirements with available heat pump technologies and their efficiency (COP).

Temperature range	Applicable processes	How feasible?	Cases
90-100°C	Cotton dyeing, desizing, scouring, bleaching & washing, mercerizing & washing	**High:** hot water heat pump, good COP	Application in other industries, nascent in textiles.
100–120 ° C 1-2 bar pressure	Drying, printing, some synthetics dyeing	**High**: best steam heat pump fit, likely to deliver good COP.	Handful of textile projects in design & implementation phases. Growing numbers in other sectors.

120–150 ° C 2–5 bar	Synthetics dyeing, higher-pressure jacket heating, some pressure vessels and sterilizers	**Medium**: Technically feasible but COP becomes more sensitive	Handful of textile projects in design & implementation phases. Growing numbers in other sectors.
150–180 ° C 6–10bar	Specialty dyeing & finishing steps	**Low:** Very few vendors & installed cases, higher capex and lower COP	Only 1 known case in any sector.
180+ 10 bar +	Stenters - heat setting	**Unavailable**	N/A

Some vendors in Asia are offering 150 °C-180 °C technology; however, we are unaware of any installed cases in any sector. The efficiency of a heat pump decreases as the gap between the waste heat source (typically around 70 °C in textiles) and the end heat demand increases. There is a gap between what is theoretically possible in terms of temperature and what has actually been demonstrated in installed cases. We have yet to see constant, stable output at higher temperatures, and demonstration cases are necessary to prove the theory. However, even these theoretically high-temperature heat pumps are unable to meet the demand of core textile processes.

An Zhou, Aii's VP of technology, is looking for "the successful transition from today's commercially mature 120°C steam heat pumps to commercially mature 150°C closed-loop steam heat pumps" to scale the deployment of the technology from 2030 onwards. Key innovation needs include the development of high-temperature heat pump standards; improved system reliability and stability; longer compressor lifetime; high-temperature lubricants and sealing materials capable of sustained operation under demanding conditions; advanced, low-cost refrigerants; stronger engineering design and manufacturing capabilities; and proven performance across diverse industrial operating environments. Achieving economically viable efficiencies, with COPs above 2.5 at 150°C steam conditions, together with extensive field deployment experience, will be critical for large-scale adoption.

Designing heat pump systems

In addition to advancements in the heat pump equipment itself, successful large-scale deployment of 150°C steam heat pumps will require significant improvements in overall system design and integration. Our engagement with heat pump vendors shows that many are only beginning to explore applications in the textile sector. As heat pumps reliant on waste heat sources are not a plug-and-play technology and, in most cases, are custom-designed for each facility, there must be an increase in technical knowledge of the vendors themselves. Additionally, recovering the waste heat to power the heat pump requires an in-depth understanding of textile processes and factory location specific-data.

Equally important is the accumulation of engineering and implementation experience. A high-performance heat pump system depends not only on the maturity of the heat pump unit itself, but also on effective system integration, heat recovery network design, steam-side engineering, process matching, and advanced control strategies. This design therefore benefits from being delivered by third-party engineers in addition to the heat pump vendors to ensure a heat pump system is correctly sized and built fit for purpose. Improper heat source and sink analysis has resulted in lengthy design processes. An Zhou has concluded that “a robust feasibility assessment must go beyond evaluating the heat pump technology itself and include a comprehensive analysis of heat sources, heat sinks, process integration opportunities, steam system requirements, operational variability, and site-specific constraints. A successful assessment should result in a system design that is correctly sized, operationally reliable, and economically viable over its lifetime. Without sufficient attention to system integration, heat recovery network design, steam-side engineering, control strategies, and long-term operating conditions, projects can suffer from lower-than-expected efficiencies, higher capital and operating costs, and increased risks of operational failures and unplanned downtime.”

Partial process vs whole facility

A key conclusion from this past year is that most facilities will only be able to pursue partial electrification in the foreseeable future; for many, even that is some years away.

From our screening of 17 textile manufacturers, the average boiler size was 17.61 MW. Currently, a single steam heat pump cannot practically exceed 2 MW, meaning that even a full heat pump installation covers only a fraction of a typical facility's single boiler steam load. Achieving meaningful electrification requires either multiple heat pumps in parallel or accepting that heat pumps serve process-specific parts of the facility's boiler demand. Our grant project with Bangjie illustrates this complexity: even at a relatively small facility, four heat pumps are required to electrify 100% of its steam load. This approach is unlikely to be economically or technically feasible for the majority of textile manufacturers.

Another issue of note is that a significant number of textile manufacturers have recently made coal phaseout investments into biomass or fossil gas, locking in that infrastructure for the medium term. These investments mean that electrification decisions for those facilities will realistically arise at the next capital replacement cycle, potentially in 15-20 years.

We also don't yet know what full electrification of a large textile facility eventually looks like. We envision this as a combination of heat pumps, electric boilers, thermal storage, and 100% electric processes, but the details remain an open question for the sector. We will be exploring the configuration of what a fully electrified facility looks like, but we are not yet in a position to offer a detailed answer. Our recommendation for now is that we continue to pursue partial electrification where it makes technical and financial sense for the textile manufacturer. Our Jiangsu Lugang project has a projection of 4,180tCO_2e annual savings from the steam heat pump displacing 33% of the facility's purchased steam needs. Aii will continue its research into full-scale electrification while providing technical and financial support for partial electrification projects.

Business case challenges

A key driver of the economic viability of heat pumps is the electricity to current fuel price ratio. The smaller the price gap, the better return on investment the heat pump will be. In the table below, we show the electricity price to fuel ratio and how it impacts project viability.

Electricity to fuel price ratio	Impact on business case

≤0.9	Competitive business case
0.9-1.1	Possibly competitive; will depend on the heat pump temperature lift & hours of operation
>1.1	Higher payback that will require financial support

From the same survey of 17 textile manufacturers across India, China, and Vietnam, we saw an average fuel price ratio of 4.02. This far exceeds what is commercially viable without brand funding support. Anecdotally, we heard concerns from these suppliers that electricity prices are not likely to go down. In fact, many of them have experienced steady increases in electricity prices as governments reassess current subsidies.

For all textile manufacturers, a substantial increase in electricity procurement is required to power a steam heat pump. So large in fact, that many textile manufacturers may not have the current transformer capacity to do so. In many regions there are limitations on transformer capacity, linked to the grid reliability and serviceability of a given area. Increasing transformer capacity adds time and cost to the investment payback period, meaning that even just one heat pump may already be physically impossible if the facility is not allowed to increase capacity or financially challenging if it can. Transformer capacity is therefore a big barrier to scaled deployment of steam heat pumps, and even more so for full electrification.

Taken together, we have seen most steam heat pump projects range from 5-8 year payback periods. Steam heat pumps are high capex investments and require serious engineering work to install, especially due to the waste heat recovery setup needed to affordably power the heat pump. Textile manufacturers tend to support decarbonization projects with payback periods of fewer than 3 years. Currently, Aii is filling this gap with grant funding from our Fashion Climate Fund. Our grant-funded projects have also received loans from their brand partners. Because the technology is still new and costly, manufacturers need a clear business case for adoption, including why the investment is strategic and what financial tools can support implementation. Aii is ensuring we have a portfolio of solutions to offer, and supporting industry alignment to drive the business case.

Steam optimization & de-steaming

The technical and economic barriers outlined above make it clear that steam heat pumps will scale faster and deliver better returns in factories that have already reduced their steam demand. Historically, textile facilities were designed around coal-fired boilers, where steam temperature and flow were relatively inexpensive and system efficiency was rarely the primary design consideration. As a result, many facilities operate with excess steam temperatures, oversized distribution systems, inefficient condensate recovery, poor heat integration, and process conditions that are higher than strictly required for product quality. In many cases, steam is used not because high-temperature steam is necessary, but because it has historically been readily available.

Crucially, bringing required steam temperatures below 150°C is a top priority, as 150°C represents a critical technological threshold for heat pump output. De-steaming and steam optimization are therefore not only parallel workstreams to electrification; they are preparation for it. Reducing the volume of steam a facility needs and lowering its required temperature and pressure directly improves heat pump feasibility, resulting in smaller system size, lower capex, better COP, and shorter payback.

Steam optimization work - like Right First Time Dyeing, upgrades to best-in-class machinery, heat recovery, condensate recovery, heat integration, steam distribution improvements and innovations such as waterless dyeing - has the potential to improve or even de-steam high temperature and inefficient textile processes. Aii is prioritizing these solutions within our Climate Solutions Portfolio and developing technical assistance to support textile manufacturers on this journey. The dual track of electrification and steam optimization will enable textile manufacturers to reduce current costs and build the sector's foundation for electrification.

Conclusion

Our ongoing work is confirming the opportunity, but also deepening our understanding of the challenges. Our work to remove technical, financial, and industry alignment barriers on this technology will continue.

We believe the next three years should focus on building the foundations for scale. Developing reliable high-temperature heat pump technologies and optimizing factory steam demand can lower implementation barriers and increase the proportion of thermal demand covered, improving system design and integration capabilities, generating real-world performance data, and creating the technical and financial confidence needed for broader adoption. By 2030, we expect commercially mature 150°C steam heat pump solutions to begin entering the market. If we can successfully bridge the gap between today's pilot projects and tomorrow's industrial-scale deployment, high-temperature heat pumps have the potential to become a transformative decarbonization technology for the textile industry.

If you are interested in learning more about how we support the industry, textile manufacturers, and brands on this journey, contact us at info@apparelimpact.org.