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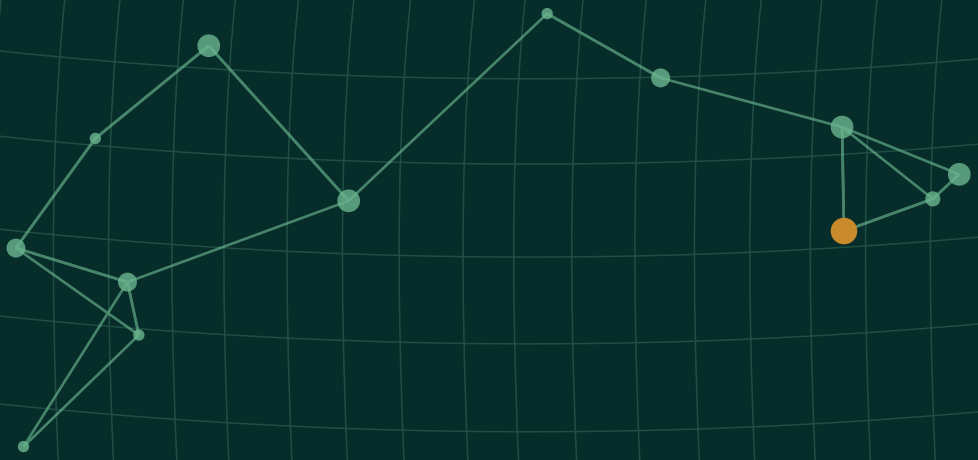
GFT RESEARCH / WARP AND SIGNAL

Water, Dye and Energy per Unit

Measuring and reducing the resource intensity of textile wet processing and garment making

wp06
RESEARCH EDITION

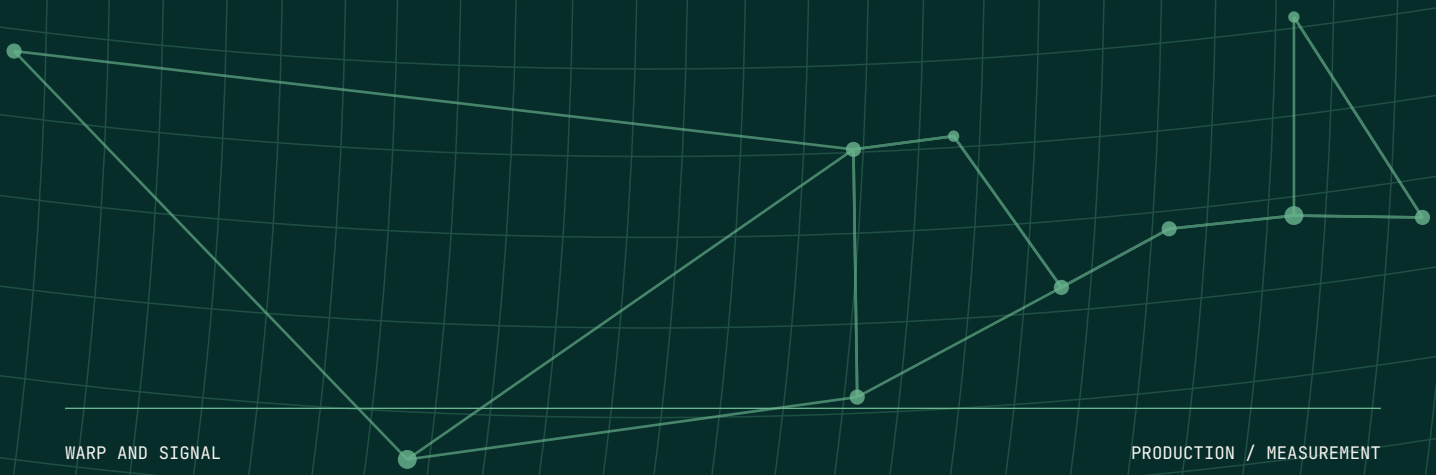
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THE GFT THESIS

Value is made where it is measured.

GFT engineers sustainable factories that capture their own data from the first shift, so raw-material economies can keep the value they grow.



Read the evidence before acting on the recommendation.

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Build the factory and its evidence as one system.

Cameroon's ambition to process more cotton locally moves environmental decisions closer to the factory gate. More local dyeing, finishing and garment making can add value, but only disciplined measurement can show whether each accepted kilogram or garment uses less water, chemistry and energy. This paper argues that resource intensity is an operating variable, not a fixed industry coefficient. It defines the factory boundary, the denominator and the meter hierarchy before comparing benchmarks. It then follows preparation, dyeing, rinsing, drying, finishing and garment making, showing why liquor ratio, dye fixation, right-first-time colour, mechanical dewatering, heat recovery and rework must be assessed as one production system. Water reuse receives equal treatment: recovery is valuable only when quality, concentrate, energy and sludge remain inside the account. Empirical mill studies and official technique guides are separated from laboratory results, supplier projections and illustrative models, so no universal saving is promised. For GFT's Cameroon textile programme, the practical answer is a batch-level resource ledger linked to recipes, metres, quality release and cost. The closing roadmap starts with a metered baseline, tests no-cost and capital measures against accepted output, and scales only verified improvements. The paper is an engineering and management framework, not investment, legal or tax advice, and it does not replace site design, legal compliance or a full life-cycle assessment.

01 Wet processing is the first factory water boundary to instrument because it dominates process water use, while garment-only sites need a separate boundary. [S03] [S01] [S24]

02 Published litres per kilogram vary too widely across mills to justify a universal design factor or saving claim. [S04] [S05] [S08]

03 Nominal machine liquor ratio is not whole-mill water intensity; batch, washing, preparation, utilities and rejected production must enter the same denominator. [S02] [S38] [S24]

04 Dye fixation and right-first-time colour are resource measures because unfixed dye and reprocessing consume chemicals, water, heat and time. [S31] [S36] [S37]

05 Thermal reduction should begin with lower bath volume, mechanical water removal and loss control before new heat supply is selected. [S16] [S17] [S26]

06 A litre or kilowatt hour cannot be interpreted without its source, location and timing; national averages do not establish site water security or electricity emissions. [S10] [S11] [S12] [S15] [S19]

07 Water reuse can reach high recovery in a documented case, but reverse-osmosis energy, concentrate and operating cost prevent a recovery-only verdict. [S06] [S33]

08 Garment making needs per-piece metering for machinery, compressed air, steam and garment washing, with rework included rather than hidden in gross output. [S28] [S30] [S07]

09 A resource baseline becomes governable when energy and water indicators have owners, normalisation rules, data-quality checks and a management cadence. [S18] [S20] [S23] [S29]

10 For Cameroon, resource measurement is a condition for turning the local-processing ambition into a credible sustainability claim, not evidence that a new venture has already achieved reductions. [R06] [R07] [S25]

GREEN FUTURE TECH

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01

PART I: DEFINE THE UNIT BEFORE REDUCING IT / THE OPERATING PROPOSITION

Local processing needs a resource ledger from the first batch

Adding value inside Cameroon requires an explicit account of the water, chemistry and energy associated with accepted production, including the work bought from suppliers.

CHAPTER 01
DECISION TEST

Adding value inside Cameroon requires an explicit account of the water, chemistry and energy associated with accepted production, including the work bought from suppliers.

Local processing needs a resource ledger from the first batch because a production decision also decides where resources are used and wastes are managed. GFT recommends linking each production record to its process boundary, resource inputs, quality release and evidence status before claiming improvement. The ledger should show both total demand and demand per accepted unit. It should distinguish operations under the proposed factory's control from purchased processing. This is an operating proposition for the Cameroon textile programme, not a statement that GFT has already measured or reduced factory impacts.

1.1

The local-processing gap moves production impacts onshore

The inherited programme evidence records about 95 percent of Cameroon's cotton fibre as exported raw and about 5 percent as processed locally. A separate inherited entry records a national target of 50 percent local processing by 2030. The original publication dates were not retained in these entries. They establish the programme's sector context, not a freshly verified national baseline or evidence of progress towards the target. The historical observation and the policy ambition must therefore remain visibly separate. [R06] [R07]

The distinction matters to this paper's argument. Processing more fibre domestically would introduce or expand the associated production stages within Cameroon wherever those stages are actually located. It would not, by itself, establish that the resulting product uses fewer resources. The destination of processing and the efficiency of processing are different questions. GFT's proposed response is to make the resource account part of the industrial design brief rather than an assertion added after the commercial case has been written.

The context in **Exhibit 1**, p. 15 explains why the question deserves attention. Its figures describe different evidential objects: an approximate inherited processing split and a national policy target. The target is not an observed operating result and should not be drawn as the end of an achieved trend. No factory capacity, implementation schedule or water requirement can be inferred from these shares alone. [R06] [R07]

EXHIBIT 01 / PERCENT OF COTTON FIBRE

The inherited processing gap creates a measurement obligation

about 95%

Raw fibre export

Inherited observation

about 5%

Local processing

Inherited observation

50%

Local processing target

National ambition for 2030

SOURCED [R06] [R07] Inherited sector context, not GFT output. Original publication dates were not recorded. The 2030 figure is a national target, not achieved production; the baseline is not a current verification.

GFT recommends beginning an industrial proposal with a product route rather than a generic claim about local value addition. Identify the incoming material, the required outgoing product and the transformations between them. Then ask which transformations are domestic, which are imported, which are owned and which are purchased. An account that stops at a garment gate cannot answer questions about the wet processing of its fabric unless that work is brought into a separate supplier record.

That recommendation also changes procurement. A request for production equipment should ask how resource use will be observed during normal production, cleaning, stoppages and restart. A request for processed fabric should ask what production boundary the supplier's figures cover. These requests should precede any savings promise. A machine catalogue or a sector ratio can support investigation, but neither provides a batch record from the proposed operation.

The resource brief should also distinguish responsibility from visibility. An operator may directly control its garment plant but only obtain evidence from an upstream processor. GFT recommends recording that difference explicitly. Missing supplier information should remain a stated gap, with a named information request, rather than being silently represented by the garment plant's own low water use. The purpose is to make the limits of control clear enough that management can act on them.

Industrial-policy reporting needs a similar separation. A processing-share indicator can describe how much material enters domestic transformation. A factory resource indicator describes the burden associated with a specified operation. Neither substitutes for the other. GFT recommends presenting the industrialisation objective alongside an independently defined resource account, so an increase in domestic activity cannot automatically be called an environmental improvement and an efficient machine cannot automatically be called successful industrialisation.

The sponsor's design brief should make that separation actionable. GFT recommends asking each proposed operating configuration to state what its resource account would include and what information would remain unavailable. Compare an integrated route with a purchased-fabric route by making the missing boundaries visible. Do not select the latter merely because its on-site account appears smaller. Equally, do not assume integration is preferable because it offers more direct control. The decision should identify which obligations would be managed internally, which would be managed through procurement and what evidence could be obtained under each arrangement. This keeps the resource question attached to the industrial choice without claiming an unsupported preference.

1.2

Wet processing sets the primary water investigation

The VTT literature review published on 16 April 2024 reports that wet processes account for approximately 60 to 90 percent of water used in textile processes. This is a literature-based prioritisation signal. It is not a measured share for a Cameroonian factory, nor a share to apply to a garment-only site's utility bill. The review also describes wet processing at different points in textile production, so a single sequence should not be assumed for every product. [S03]

For a proposed operation that includes preparation, dyeing or wet finishing, GFT recommends investigating those duties early. The first question should be where fresh water enters and where process water leaves, not which machine advertises the largest percentage saving. The investigation should connect the production route to the actual water circuits. It should identify what can be isolated for measurement and what remains shared with utilities or other operations.

IFC's textile manufacturing guidance connects water use with freshwater demand, wastewater and sludge, and the energy needed for heating. That link makes the operating question wider than the volume entering a dyeing machine. A reduction claim needs a consistent account of what enters, what is heated, what leaves and what treatment or residual-management duty remains. The guideline provides an engineering rationale for reading these burdens together. [S01]

GFT therefore recommends treating water, chemistry and energy as connected records rather than a combined score. Keep the original units and identify the common batch or production period. A water result should be accompanied by the relevant quality decision and any change in chemical or heat demand. This preserves the ability to investigate a trade-off instead of allowing a favourable weighted total to hide an unfavourable physical result.

Consider a proposed trial that changes a washing sequence. The trial brief should ask whether production reaches the same release requirement, whether a corrective cycle occurs and whether the apparent reduction has moved a duty elsewhere. Those are questions to test, not assumed consequences. The ledger should retain unsuccessful trials because excluding them would give management an incomplete picture of the method's repeatability and the resources spent learning how to operate it.

The initial water investigation should be proportionate to the proposed route. A garment operation receiving already finished fabric needs a different measurement plan from an integrated processor. For the former, GFT recommends verifying whether any washing, printing, steam finishing or other water-using duty is actually present before designing a dyehouse-style audit. For the latter, identify the wet stages and their interfaces before deciding which meters offer useful separation. The process map, rather than a company label, should determine the account.

GFT recommends keeping sanitary uses and shared site services visible alongside production, with a documented rule for any allocation. This does not require assigning every litre to a product on the first day. It requires showing which volume is measured, which is allocated and which is unresolved. A complete-looking product ratio assembled from unexplained allocations is less useful for operating decisions than a transparent total with a bounded coverage gap.

> **GFT NOTE**
>
> Commission the resource map with the production route. Ask the process engineer, utilities lead and quality lead to agree where a batch starts, where acceptance occurs and which shared services sit outside its direct readings. Require a visible unresolved category until those services can be measured or allocated on a defensible basis. Do not set a reduction target by subtracting a supplier's promise from an unmeasured baseline.

The practical output of this investigation should be a set of answerable questions. Which circuit needs a meter? Which supplier needs to provide a process record? Which quality release must accompany a trial? Which uncertainty prevents a comparison? GFT recommends using the answers to commission the next investigation, rather than turning a broad literature share into a presumed split of local consumption.

During design review, GFT recommends tracing a proposed batch through this map as a practical exercise. Ask where a start reading would come from, who could associate it with the batch and where any subsequent correction would be recorded. Then follow the same batch through acceptance or rejection. If the exercise cannot locate a reading, an identifier or a responsible role, record a design question before selecting software. The exercise does not prove that a proposed instrument will be accurate or that a process will perform well. It establishes whether the proposed account could be assembled at all and identifies the evidence that commissioning must subsequently test.

1.3

Integrated and garment-only factories require different accounts

The Sustainable Apparel Coalition's December 2022 Higg FEM technical paper describes separate water and energy reporting for facility types within a vertically integrated operation. It gives the example of a facility making fabric and finished products. The document is preparatory and explicitly warns that the eventual frame-

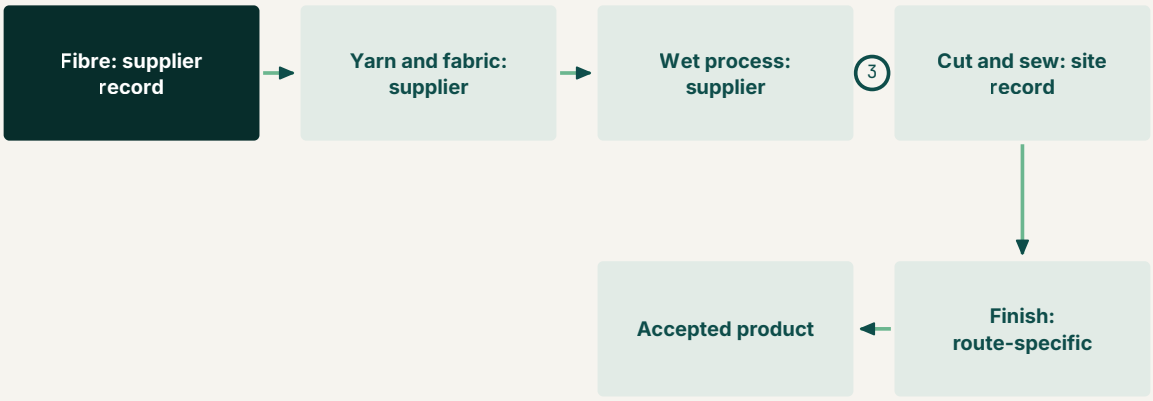
work may differ. Here it supports the accounting principle of preserving process boundaries; it is not presented as a current certification rule or evidence of GFT conformance. [S24]

For this paper, GFT recommends a proposed garment-centred configuration that separates cut, make, trim and finishing from any upstream work purchased from partners. This is a planning boundary, not a claim that a particular operating plant or partner network exists. If upstream work is later brought inside the facility, the ledger should preserve its separate account. A change in ownership should change the responsibility field without erasing the physical process record.

The illustrative map in **Exhibit 2**, p. 18 shows this proposed separation. Its sequence is deliberately simplified: the VTT review describes wet processing at different production stages. Procurement and site design must therefore replace the drawing with the actual product route. The diagram specifies no GFT asset, contracted processor, installed capacity or measured flow. [S03]

EXHIBIT 02 / ILLUSTRATIVE RESPONSIBILITY MAP

Purchased processing needs a separate resource account



3. Boundary handover

ILLUSTRATIVE [S03] [S24] GFT planning illustration, not an operating footprint. A simplified route is shown; wet processing may occur at other stages. Partnered and owned labels are proposed account boundaries, not existing commercial relationships.

The handover is the critical design feature. GFT recommends that incoming fabric retain its supplier identity, product description and processing route. If resource data are available, they should retain the supplier's period, denominator and allocation basis. If they are unavailable, procurement should record the omission. A purchased kilogram should not acquire a precise environmental history simply because the receiving plant has accurate electricity meters.

Inside an integrated facility, GFT recommends keeping departmental accounts before consolidating the site total. The same principle should govern a proposed garment operation with shared services. Direct readings belong to the process they serve.

Shared readings need an allocation rule, and any remainder should remain visible. Consolidation should reconcile those records; it should not replace them with a single ratio that cannot identify a corrective action.

Purchased steam provides a useful boundary test. GFT recommends recording delivered heat as purchased heat at the receiving boundary, with its measurement basis retained. Fuel used by an external supplier belongs in an explicitly wider account if evidence is available. It should not be silently combined with on-site fuel and counted again as delivered heat. The chapter's point is the need for a declared rule; the detailed energy method belongs later in the paper.

The same discipline applies when production is outsourced during disruption. GFT recommends marking which orders move to another processor and whether their resource records are included in the reporting period. Otherwise a lower site total could merely reflect work transferred away. This is an analytical possibility to guard against, not a reported GFT event. The receiving organisation should be able to explain a boundary change before interpreting a trend.

To make the account usable, GFT recommends assigning responsibility for each interface. Production should identify the route actually run. Quality should identify accepted output. Utilities should maintain the reading boundary. Procurement should obtain and qualify supplier evidence. These are proposed responsibilities, not GFT staffing claims. The resource owner should be able to follow an exception across those responsibilities without losing the link to the order or batch.

An illustrative supplier handover shows why the wording matters. Suppose procurement receives a water-intensity statement for a fabric delivery but the statement covers the supplier's entire annual product mix. GFT recommends retaining that statement as supplier-period evidence, without relabelling it a direct measurement of the delivered batch. Ask for the covered processes, measurement period, output definition and allocation rule. If the supplier cannot provide them, the receiving site can still record what it knows about its own operations. The combined product account should preserve the supplier gap. This avoids both discarding useful contextual information and granting it a precision that the underlying record does not support.

1.4

Absolute load and unit intensity answer different questions

A unit ratio answers how much resource is associated with a defined amount of output. An absolute total answers how much resource the operation demands over the reporting period. GFT recommends keeping both on the same management view because their movement can differ. A lower ratio is not sufficient evidence of lower total demand, and a lower total is not sufficient evidence that the production process has become more efficient.

The distinction can be demonstrated without borrowing a factory benchmark. The following illustrative case assumes comparable fabric, processing route, release criteria and reporting periods. It uses accepted kilograms as the denominator and assumes

every water total covers the same complete intake boundary. The values are invented to expose the arithmetic. They are neither estimates of Cameroon demand nor observed GFT performance.

> **WORKED EXAMPLE: IMPROVED INTENSITY CAN COEXIST WITH HIGHER INTAKE**
>
> An illustrative baseline accepts 1,000 kg while taking 100,000 litres. Its intake intensity is 100,000 / 1,000 = 100 litres per accepted kg. An illustrative later period accepts 1,500 kg while taking 120,000 litres. Its intensity is 120,000 / 1,500 = 80 litres per accepted kg. The unit ratio falls by (100 - 80) / 100 = 20 percent, while absolute intake rises by (120,000 - 100,000) / 100,000 = 20 percent. Accepted output rises by 50 percent. All inputs are assumed solely for this teaching case.
>
> At the illustrative later output, holding the original intensity constant would imply 1,500 × 100 = 150,000 litres. The difference from the illustrative later intake is 30,000 litres. This is a calculated comparison against an assumed constant-intensity reference. It is not an observed reduction in total intake, and it cannot be called a verified saving without evidence that the periods and production conditions are comparable.

The illustrative ledger in **Exhibit 3**, p. 20 keeps these statements separate. It makes no claim about discharge, chemistry, energy or local water availability. Those variables were not supplied to the teaching case and cannot be inferred from its intake arithmetic.

EXHIBIT 03 / ILLUSTRATIVE COMPARABLE REPORTING PERIODS

A lower unit ratio can accompany higher total intake

Measure	Baseline	Later
Accepted output (kg)	1,000	1,500
Intake (litres)	100,000	120,000
Litres / accepted kg	100	80

ILLUSTRATIVE All inputs assumed. Intake intensity = litres / accepted kg. Output rises 50%, intake rises 20%, and intensity falls 20%. Constant-intensity later intake = 1,500 × 100 = 150,000 litres; its 30,000-litre difference is a conditional reference comparison, not a measured saving.

GFT recommends asking separate decision questions of the results. The production team should investigate whether the process uses less water under comparable conditions. The utilities team should assess whether the larger total can be supplied and managed. The sponsor should decide whether the proposed production volume fits the infrastructure and wider assessment. A common dashboard can support these decisions, but a single percentage should not stand in for all of them.

Accepted output also needs a release boundary. GFT recommends excluding unresolved material from the accepted denominator until its status is established, while retaining the resources already spent on it. The specific treatment of work in progress

and later release needs a consistent rule. This opening chapter does not prescribe the detailed allocation method. It establishes why that method must be agreed before a favourable trend is interpreted.

The absolute account should preserve each resource category rather than aggregate unlike quantities. GFT recommends showing freshwater intake, discharge, purchased electricity, fuel and purchased heat in their own units, with chemistry recorded by relevant input categories. The manager can then ask whether an apparent reduction in one record coincides with an increase in another. Any wider impact assessment requires an additional method and evidence beyond this operating ledger.

Where output changes sharply, GFT recommends retaining both the raw comparison and the explanation of relevant conditions. Product route, shade mix, accepted quality and operating time should remain available for investigation. An adjusted result can be useful, but its adjustment rule should be visible. The chapter's illustrated arithmetic is transparent precisely because it states its simplifying assumptions instead of claiming to have normalised an actual production history.

Interpretation also needs a reporting cut-off. GFT recommends preserving the status of production at the close of the period, rather than rewriting earlier reports whenever material is subsequently released. Any later revision should be explicit and reproducible. An operation whose output remains under assessment may still have consumed water and energy. Management needs to see that demand even when a provisional unit ratio cannot yet be reported. The useful response is to show the total, explain the pending denominator and identify the record that will resolve it. A blank or provisional ratio should never be silently replaced with a favourable assumed acceptance result.

1.5

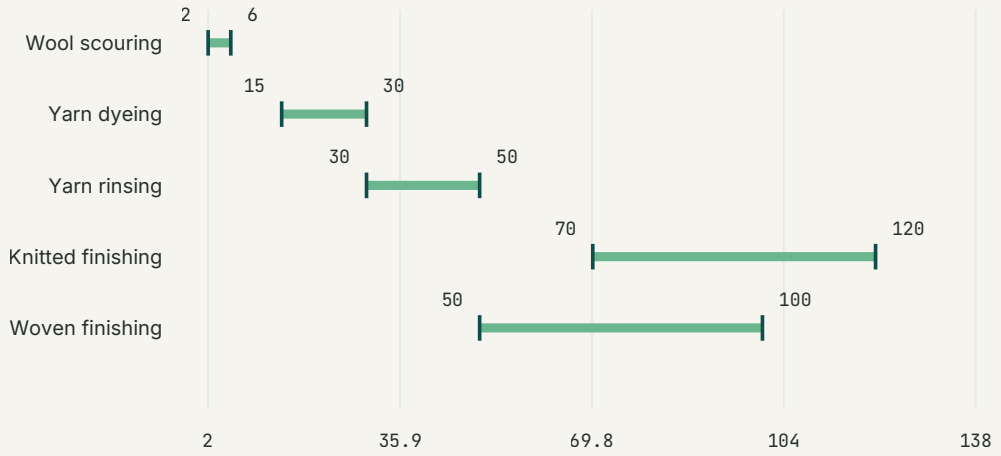
Benchmark ranges locate investigations rather than promises

IFC's April 2007 guideline presents process-specific resource benchmarks for comparison and cautions that their underlying installation set is limited. Its water ranges include wool scouring at 2 to 6 litres per kg, yarn dyeing at 15 to 30, yarn rinsing at 30 to 50, knitted-fabric finishing at 70 to 120 and woven-fabric finishing at 50 to 100. These are different processes, not interchangeable whole-factory coefficients or Cameroon observations. [S01]

The range encoding in **Exhibit 4**, p. 22 preserves the published endpoints. A single bar or midpoint would hide information relevant to screening. Wool scouring remains in the comparison to show that the guideline covers different fibre routes; it is not proposed as a cotton-process allowance. The chart must be read with its process labels, period and limited-installation qualification. [S01]

EXHIBIT 04 / LITRES PER KG AT THE STATED PROCESS BOUNDARY

Published water ranges describe different process boundaries



SOURCED [S01] IFC, April 2007, Table 3; based on a limited installation set and provided for comparison only. Dyeing and rinsing are separate entries. Wool is a different fibre route. Endpoints are published ranges, not confidence intervals, Cameroon measurements or guaranteed targets.

Empirical studies bring different boundaries. The PLOS study published on 31 July 2023 used questionnaire-based evidence from 18 Bangladesh wet-processing factories selected through snowball sampling. It reports mean groundwater use of 164 litres per kg, dyehouse water of 136 and wastewater of 119. Those values describe the study's sample and definitions. They are not a random national sample, a closed balance for a proposed plant or an accepted-output benchmark. [S04]

The separate Textiles study published on 28 September 2022 analyses 15 Bangladesh dyeing mills using 2019 data. Its reported groundwater KPI ranges from 99.15 to 198.20 litres per kg of dyed fabric, with a mean of 138.26. The observation year, denominator and sample remain attached to that result. Its forward reduction scenarios should not be confused with the measured baseline, and neither establishes a local operating target for GFT. [S05]

The May 2015 report by the 2030 Water Resources Group places Bangladesh water use in a sector and scenario analysis. It reports an IFC-attributed factory consumption estimate of up to 250 to 300 litres per kg of fabric. That contextual estimate has a different evidential basis from the later mill samples. Averaging these figures together would remove their meaning rather than improve precision. [S08]

The editorial comparison in **Exhibit 5**, p. 23 therefore records permitted uses and cautions instead of placing incompatible figures on a common performance scale. Its classifications are GFT's interpretation of the opened documents, not a ranking supplied by their authors. The table is a reading aid for commissioning investigations. [S01] [S04] [S05] [S08]

EXHIBIT 05 / GFT INTERPRETATION OF PUBLISHED EVIDENCE

Source boundaries determine what a benchmark can support

Evidence	Boundary	Use and caution
IFC, 2007	Process kg; limited installations	Screen process duties; not a site guarantee
PLOS, 2023	18 Bangladesh factories; textile kg	Compare water categories; non-random sample
Textiles, 2022	15 mills, 2019; dyed fabric kg	Investigate mill variation; not accepted kg
2030 WRG, May 2015	Bangladesh sector analysis; fabric kg	Read scenario assumptions; not a new-site design

DERIVED [S01] [S04] [S05] [S08] Derived editorial classification, not statistical pooling. Publication year is distinct from observation year. Each document supports investigation at its own boundary; none supplies a verified Cameroon plant baseline or a GFT reduction.

GFT recommends using this evidence to define questions for equipment suppliers and site investigations. Ask what a proposed guarantee includes, which product it assumes and how the test will be run. Require the comparison to name the process boundary and quality conditions. A published range can suggest where to look, but a procurement target needs evidence at the proposed operation's boundary, with a test that can distinguish failure from success.

Before converting a benchmark into a design input, GFT recommends asking the engineer to document its intended use. Preliminary screening, instrument selection and final utility sizing require different confidence. Where a design must proceed before production data exist, retain the value as an estimate with its source, margin and validation plan. Do not let a provisional coefficient become a permanent baseline simply because it appears in an approved spreadsheet.

The procurement comparison should preserve exclusions as carefully as headline values. GFT recommends asking whether a proposed performance figure includes preparation, washing, cleaning, sampling, reprocessing and the relevant shared utilities. Ask whether it describes a machine test, a production campaign or a whole-site account. These questions do not imply that every supplier figure must cover every duty. They make the figure's permitted use inspectable. Competing offers can then be compared at a common declared boundary, with remaining differences stated, rather than ordered by whichever number happens to be smallest. The resulting comparison remains provisional until the proposed operating conditions can be tested.

1.6

GFT's position is measurement before environmental claims

GFT's position is that a resource statement should be no broader than its record. A site electricity result describes a site electricity boundary. A batch water result describes its measured and allocated water boundary. A supplier estimate remains an

estimate. GFT recommends preserving those distinctions through management reporting and any later public wording, so a narrow operational improvement cannot be read as an established reduction across an entire product life cycle.

The opening chapter's practical deliverable is therefore a measurement contract. GFT recommends that it name the product boundary, accepted-output rule, resource categories, reporting period and responsible roles. It should also state how missing readings, shared services, outsourced work and changes to the process will be treated. These definitions give later chapters a common decision boundary without predetermining their detailed technical methods.

The contract should require an evidence status beside each significant result. GFT recommends distinguishing direct readings, calculations from readings, estimates and proposed scenarios. Preserve the underlying record and the calculation version. An estimate may be useful for planning, but it should not silently become measured evidence when copied into a dashboard. A change in evidence status needs an identifiable reason and supporting record.

The claim itself should be drafted with its evidence test. GFT recommends recording the intended reader, the physical boundary and the comparison being asserted before a trial begins. A statement about lower intake at unchanged accepted production requires different proof from a statement about lower intensity during expansion. A statement about supplier engagement requires different proof from a measured supplier reduction. If the available record supports only the narrower statement, publish only that statement after the appropriate internal approval. This approach makes communication part of the measurement design, while leaving the actual outcome open to what the trial demonstrates.

GFT also recommends a short challenge process before a resource claim is released. Can the result be traced to its readings? Does its output have the stated quality release? Is the comparison boundary unchanged or explicitly reconciled? Are unsuccessful runs included? Is any supplier contribution missing? The purpose is to expose the condition that could change the conclusion. A claim that survives these questions is more useful than an attractive ratio with an unknown denominator.

For the proposed Cameroon programme, the next useful action is to commission this contract against the intended product route and supplier boundary. GFT recommends collecting the first comparable production records before approving an environmental performance target. During commissioning, use the ledger to identify missing instruments and unresolved allocations. During trials, use it to compare methods. During operation, use it to determine which exceptions need corrective work.

The commissioning handover should include a demonstrated reading path. GFT recommends selecting a completed production record and following it from the original resource reading through its calculation to the management result. A second person should be able to reconstruct the stated boundary and identify any assumed allocation without relying on an oral explanation. If that cannot be done, the handover should identify the missing record and an action owner. This is a proposed acceptance exercise, not a report of an exercise already performed. Its value is to test whether the ledger can support a decision after the person who assembled it is no longer in the room.

The sponsor should retain the right to withhold a reduction claim while continuing useful engineering work. GFT recommends treating an unresolved comparison as an information problem with a defined next test. Production can continue to generate evidence, and procurement can continue to clarify guarantees, without giving an incomplete result a stronger label. The ledger should help the team move from uncertainty to a reproducible conclusion, rather than create pressure to declare success before the necessary account exists.

This framework is an engineering and management recommendation. It is not investment, legal or tax advice, a compliance determination, a certification statement or a substitute for site-specific environmental assessment. No GFT reduction, client performance or installed resource system is asserted here. The paper defines the evidence that would be needed before reporting those outcomes and leaves their achievement to a documented operating test.

The resource ledger makes the Warp and Signal proposition concrete: production provides the material route, and measurement provides the record needed to judge it. GFT recommends keeping the record close enough to the batch that a manager can identify the action behind a result. Local processing can then be discussed through visible choices about inputs, accepted output and responsibility, with the remaining uncertainty retained alongside the answer.

The first batch should leave both a product and an account.

CHAPTER SOURCE NOTES

R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.

R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S24 Sustainable Apparel Coalition. 2022.

S04 PLOS Sustainability and Transformation. 2023-07-31.

S05 MDPI, Textiles. 2022-09-28.

S08 2030 Water Resources Group, World Bank. 2015.

GREEN FUTURE TECH

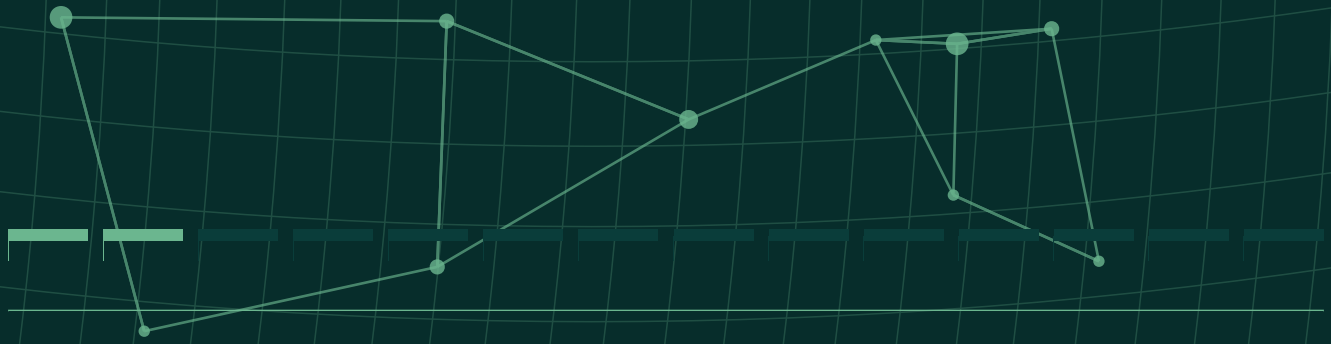
LIMITED / HONG KONG SAR

02

PART I: DEFINE THE UNIT BEFORE REDUCING IT / UNITS AND NORMALISATION

The denominator decides whether efficiency is real

A per-unit ratio is meaningful only when output, quality release, product mix and allocation rules remain visible beside it.



CHAPTER 02
DECISION TEST

A per-unit ratio is meaningful only when output, quality release, product mix and allocation rules remain visible beside it.

A resource intensity ratio such as litres of water per kilogram of fabric or kilowatt hours of electricity per garment is an engineering construct, not a direct meter reading. [S24] [S29] Meters record cumulative volumes of water, steam, gas, electricity and chemical solution passing a pipe or cable, whereas production logs record rolls of cloth, dye lots, cut bundles and packed garments leaving workstations. [S18] [S24] Efficiency is real only when the denominator of that ratio is restricted to accepted output released to the next stage, converted between fabric mass and garment count through measured physical parameters, separated by facility type before shared utilities are allocated, normalised for product mix and operating volume, reconciled against a closed site mass and energy balance, and governed by explicit baseline-revision rules. [S18] [S24] [S29] [S37] [S0201] When any of those six conditions fails, a factory can report a falling per-unit ratio while actual freshwater withdrawals, fuel burn and effluent discharge per saleable unit are rising. [S04] [S29] [S37]

For Green Future Tech Limited (GFT), Hong Kong SAR, denominator discipline is a precondition for industrial execution rather than an after-the-fact reporting exercise. In GFT's source base prepared on 31 January 2024 and refreshed with 2026 annotations, about 95 percent of Cameroon's cotton fibre is exported raw and only about 5 percent is processed locally, while the national industrialisation strategy targets 50 percent local processing by 2030. [R06] [R07] Moving from raw lint export to domestic spinning, knitting, weaving, wet processing and garment manufacture shifts water, chemical and thermal loads onto domestic catchments and power networks. [S01] [S03] Because GFT's three-part Cameroon textile programme links factory feasibility, performance-management system design and digital strategy around the thesis that production is the warp and measurement is the weft, the unit denominator is the crossing point between physical production and environmental proof. [R06] [R07] This chapter specifies the formulas, conversion rules, allocation drivers, regression checks and baseline governance needed before any saving claim is accepted. It is an engineering and management framework, not investment, legal or tax advice.

2.1

Accepted output prevents rejected production from improving the ratio

An operational resource ratio measures efficiency only if its denominator counts good output that passes quality release at the process boundary, while its numerator retains all water, energy and chemistry consumed by rejected, stripped, re-dyed or repaired lots. [S37] In many mills, production departments log gross machine loading: every kilogram of cloth loaded into a dyeing machine or stenter is added to monthly volume regardless of whether the lot passed first time or required a corrective cycle. [S29] [S37] When a batch of cotton fabric fails colour matching and is re-dyed, counting its mass twice in the monthly denominator treats rework as fresh production. Under that convention, a dyehouse suffering a surge in shade failures can appear to improve its litres per gross kilogram, because corrective washes often use less water than a full pretreatment-plus-dye cycle while doubling recorded weight. [S37]

2.2 GROSS THROUGHPUT REWARDS REPROCESSING UNLESS THE DENOMINATOR IS GATED BY QUALITY RELEASE

Right-first-time production in textile dyeing means that every batch of dyed fabric achieves the target shade on the first attempt, as verified against the release standard, without corrective reprocessing such as stripping, shade topping or re-dyeing. [S37] Empirical dyeing research shows that achieving right-first-time colour reduces water consumption, thermal and electrical energy demand, effluent generation, chemical usage and machine time simultaneously. [S37] Conversely, when hard water, unstable alkali dosing or uneven preparation causes dye precipitation or unlevelness, corrective reprocessing consumes extra dyestuff, auxiliaries, water, steam and machine hours without producing an extra kilogram of saleable cloth. [S31] [S37]

If the environmental ledger takes its denominator from gross machine throughput rather than quality-released output, the sustainability indicator detaches from physical reality. [S29] [S37] At the boundary between the dyehouse and the cutting room, only fabric rolls that pass instrumental colour-difference tolerances, fastness checks and physical inspection can be cut into saleable garments. [S31] [S37] Any water, steam or electricity spent on rolls that are scrapped or routed through a stripping bath is an overhead burden borne by the accepted rolls. GFT therefore defines operational intensity at each stage by keeping all gross resource inputs in the numerator and restricting the denominator to net accepted output released to the next stage, as structured in **Exhibit 6**, p. 28. [S24] [S29] [S37] [S0201]

EXHIBIT 06 / FORMULA ARCHITECTURE LAYERS

The unit formula joins resource, quality and product identity



ILLUSTRATIVE [S24] [S29] [S37] [S0201] Illustrative formula architecture designed by GFT using separate facility-tracking rules from S24, specific-energy benchmarking from S29, right-first-time reprocessing logic from S37 and baselining rules from S0201.

The layered structure in **Exhibit 6**, p. 28 shows why a ratio cannot be audited from its headline figure alone. [S24] [S29] [S0201] At the base layer, the numerator captures every metered input entering the process boundary, including initial bath fills, rinses, corrective additions, re-dyes, allocated utilities and an explicit reconciliation residual against the main meter. [S18] [S24] [S37] At the second layer, the denominator gate strips out rejected mass and prevents reprocessed batches from being counted twice. [S37] At the third layer, normalisation variables attach product identity and utilisation context so ratios are compared across equivalent conditions. [S02] [S04] [S29] [S0201] Notice that **Exhibit 6**, p. 28 is an illustrative accounting architecture: it defines GFT's calculation structure, not a measured factory result.

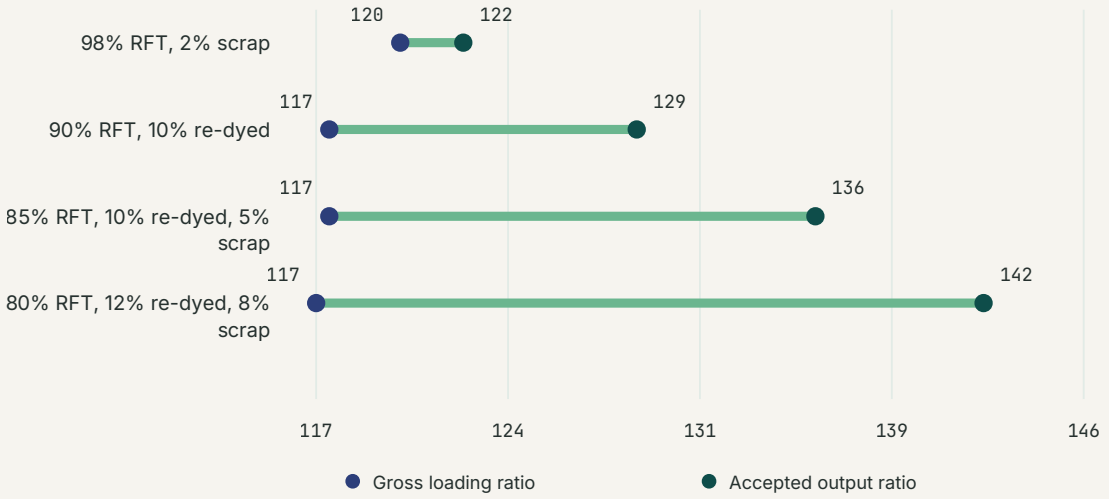
2.3 RIGHT-FIRST-TIME COLOUR AND FIRST-PASS GARMENT YIELD BELONG INSIDE THE SUSTAINABILITY FORMULA

Extending right-first-time logic into the denominator exposes how quality failures inflate resource intensity across wet processing and garment assembly. [S37] When a batch fails shade release, it is shaded with a corrective addition, stripped and re-dyed, or scrapped. [S37] In all three cases, numerator water, energy and chemical inputs rise, while accepted output either stays flat or shrinks. [S31] [S37]

The divergence between gross-output and accepted-output accounting is shown in **Exhibit 7**, p. 29. [S37] Across four illustrative states with rising rework and scrap, dividing metered water by gross machine loading (counting re-dyed weight in the denominator) makes intensity appear flat or declining, whereas dividing by accepted fabric reveals the true penalty of quality failure. [S37]

EXHIBIT 07 / ILLUSTRATIVE L PER KG

Gross production can flatter intensity relative to accepted output



ILLUSTRATIVE [S37] Illustrative model of a 10,000 kg cotton batch schedule with 120 L/kg first-pass water use, 90 L/kg corrective re-dye water use and stated reject shares. Direction of reprocessing penalty follows S37; values are illustrative.

In **Exhibit 7**, p. 29, each paired state uses an illustrative 10,000 kg cotton schedule with 120 L/kg first-pass water demand (1,200,000 litres initial water) and 90 L/kg corrective re-dye water demand. [S37] In the second row (`90% RFT, 10% re-dyed`), 1,000 kg undergo a 90 L/kg re-dye, raising total water to 1,290,000 litres. Counting the re-dyed 1,000 kg twice in gross throughput divides 1,290,000 litres by 11,000

gross kilograms to report 117.3 L/kg, whereas true intensity across the 10,000 accepted kilograms is 129.0 L/kg. In the fourth row (`80% RFT, 12% re-dyed, 8% scrap`), 1,200 kg are re-dyed (total 1,308,000 litres) and 800 kg are scrapped, leaving 9,200 accepted kilograms: gross-loading accounting reports 116.8 L/kg across 11,200 gross kilograms, whereas accepted-output accounting exposes 142.2 L/kg. [S37] Because **Exhibit 7**, p. 29 is an illustrative model, it proves the accounting mechanism rather than claiming an observed site reject rate.

WORKED EXAMPLE: HOW GROSS MACHINE LOADING HIDES A REPROCESSING WATER AND ENERGY PENALTY

Consider an illustrative weekly schedule of 10 batches of knitted cotton fabric, each weighing 1,000 kg conditioned dry mass (10,000 kg total order mass). Assume each initial cycle consumes an illustrative 130 L/kg of softened water (130,000 litres per batch) and 2.50 kWh/kg of electricity (2,500 kWh per batch), within the range of empirical dyehouse surveys. [S04] [S05]

Suppose 8 batches pass shade release first time (`80 percent` illustrative first-pass yield), while 2 batches (2,000 kg) fail due to water-hardness variation. [S37] Both failed batches undergo stripping and re-dyeing at an illustrative 110 L/kg of water (220,000 litres total) and 2.10 kWh/kg of electricity (4,200 kWh total). After reprocessing, 1 re-dyed batch (1,000 kg) passes release and 1 batch (1,000 kg) is scrapped. Weekly dyehouse meters record an illustrative `1,520,000 L` of water and `29,200 kWh` of electricity. Compare three denominator definitions:

1. **Uncontrolled gross machine loading (12,000 kg illustrative):** Counts 10 initial loads plus 2 re-dye loads, yielding `1,520,000 / 12,000 = 126.7 L/kg` and `29,200 / 12,000 = 2.43 kWh/kg`. Both illustrative ratios look better than the first-pass baseline (`130.0 L/kg` and `2.50 kWh/kg`), rewarding rework. [S37]
2. **Gross fabric entered (10,000 kg illustrative):** Counts the 10 batches entered without subtracting scrap, yielding `152.0 L/kg` and `2.92 kWh/kg` (illustrative), which still credits 1,000 kg of unusable scrap. [S37]
3. **GFT accepted output released (9,000 kg illustrative):** Counts only the 9 accepted batches released to cutting, exposing true intensities of `1,520,000 / 9,000 = 168.9 L/kg` (`30.0 percent` above baseline) and `29,200 / 9,000 = 3.24 kWh/kg` (`29.6 percent` above baseline, illustrative). [S37]

This illustrative case is not a GFT plant forecast; it demonstrates why first-pass yield (`80 percent` illustrative) and net acceptance yield (`90 percent` illustrative) must accompany every resource ratio. [S37]

2.4

Fabric mass and garment count need a controlled conversion

A textile chain changes its physical unit downstream: spinning, knitting, weaving and wet processing weigh output in kilograms of yarn and fabric, whereas cutting, sewing and garment washing count output in pieces. [S04] [S07] [S30] Combining upstream wet-processing benchmarks (litres or kilowatt hours per kilogram) with downstream garment benchmarks (megajoules or litres per piece) through an unmeasured conversion factor introduces errors larger than plant efficiency gains. [S04] [S30]

2.5 AREAL DENSITY, CUTTABLE WIDTH AND MARKER YIELD GOVERN THE BRIDGE FROM KILOGRAMS TO PIECES

Converting between fabric mass and garment count requires measured physical parameters rather than a static "average shirt weight." [S0202] Five variables govern the bridge: fabric areal density in grams per square metre (GSM), which represents the mass in grams of one square metre of fabric; [S0202] usable cuttable roll width; [S0202] size-weighted net pattern area; marker utilisation efficiency (including selvedge, roll-end and defect-splice losses); and sewing acceptance yield.

Experimental knitting data prove that machine settings alter these conversion parameters even at constant yarn count. [S0202] In a 2025 study of weft-knitted 100 percent cotton plain jersey made from 30/1 Ne (19.68 Tex) combed yarn on a 24-gauge circular knitting machine, varying loop length across 2.77 mm, 2.84 mm and 2.90 mm shifted dry-relaxed areal density from 130.1 GSM down to 112.9 GSM (13.2 percent variation). [S0202] At constant loop length, changing mechanical sinker timing between retracting (0.2 mm) and forwarding (0.2 mm) kept areal density nearly unchanged (128.8 GSM versus 129.6 GSM at 2.77 mm) but shifted relaxed fabric width by around 7 percent (from 56.41 cm to 60.38 cm at 2.77 mm, and up to 66.78 cm at 2.90 mm) and width-wise contraction by around 5 percent, with no visible difference under D-65 inspection lighting. [S0202] Because cutting markers require a specific minimum width, a 5 to 7 percent width shift or GSM drift alters selvedge waste and fabric mass per cut garment. [S0202]

CONTROLLED CONVERSION FROM CONDITIONED FABRIC MASS TO ACCEPTED GARMENT PIECES

To join a wet-processing ledger in accepted fabric kilograms ($M_{fab,acc}$) to a garment ledger in accepted pieces ($N_{gar,acc}$), GFT records five lot parameters:

1. **Conditioned areal density (A_{GSM}, in g/m2):** Measured on relaxed finished rolls before spreading. [S0202]
2. **Net pattern area (S_{pat}, in m2/piece):** Size-weighted surface area of pattern pieces per garment (illustrative formula input). [S0202]
3. **Net garment mass ($m_{gar,net}$, in kg/piece):** $m_{gar,net} = (A_{GSM} * S_{pat}) / 1{,}000$ (1,000 g/kg, illustrative formula input). [S0202]
4. **Cutting utilisation yield (η_{cut}, fraction in (0,1]):** Net pattern mass divided by finished roll mass issued to cutting (illustrative formula input).
5. **Sewing acceptance yield (η_{sew}, fraction in (0,1]):** Accepted garments ($N_{gar,acc}$) divided by cut bundles entering sewing (illustrative formula input). [S37]

Gross accepted fabric required per accepted garment ($m_{fab,req}$, in kg/piece) is $m_{fab,req} = (A_{GSM} * S_{pat}) / (1{,}000 * \eta_{cut} * \eta_{sew})$. [S0202] In an illustrative case with A_{GSM} = 130.0 g/m2, [S0202] S_{pat} = 1.25 m2/piece, η_{cut} = 0.82 and η_{sew} = 0.97, net garment mass is 0.1625 kg/piece, but required finished fabric is 0.2043 kg/piece (25.7 percent higher, capturing 18 percent illustrative cutting waste and 3 percent illustrative sewing rejects).

2.6 GATE-TO-GATE GARMENT BENCHMARKS PROVE PER-PIECE ACCOUNTING WITHOUT SUPPLYING A UNIVERSAL FACTOR

At the garment floor, reporting intensity per accepted piece is well established when boundaries stay explicit. [S07] [S30] A 2024 gate-to-gate study of Bangladesh T-shirt production reported specific energy consumption of 12 MJ/piece (3.33 kWh/piece) and specific emissions of 0.94 kg CO2/piece, 1.69 g CO/piece, 3.53 g CH4/piece, 4.1 g NOx/piece and 0.89 g SOx/piece across machinery, steam generation and compressors. [S30] In wet garment finishing, a UNIDO project at New Amico in Tunisia projected that three E-flow machines would cut jeans-washing water by 13 litres per piece. [S07]

Both studies validate per-piece denominators (MJ/piece, L/piece), yet neither supplies a universal conversion factor for Cameroon. [S07] [S30] A knitted T-shirt (12 MJ/piece) differs fundamentally from woven workwear or washed denim (13 L/piece projected saving). [S07] [S30] In Cameroon, where 2024 apparel demand was about 8.0 pieces and US$94.70 per person, [R26] a plant making knitwear, uniforms and institutional textiles will span wide piece weights. GFT therefore logs both accepted pieces ($N_{gar,acc}$) and net garment mass ($M_{gar,acc}$) on every order. [S24] [S30]

2.7

Process subtotals make allocation auditable

Combining multiple manufacturing stages behind one utility meter hides inefficiency if total site water or energy is divided by a single aggregate output figure. [S24] [S0201] VTT Technical Research Centre of Finland estimates that wet processes consume 60 to 90 percent of textile process water, [S03] while composite-plant analysis shows preparation, dyeing, printing and finishing demand 50 percent of thermal energy. [S16] Pooling a dyehouse with a dry sewing floor yields a hybrid ratio that neither manager can act upon. [S24]

2.8 INTEGRATED MILLS MUST SEPARATE FABRIC PRODUCTION FROM FINAL GARMENT ASSEMBLY BEFORE COMPUTING RATIOS

The Sustainable Apparel Coalition's Higg Facility Environmental Module (FEM) 4.0 Technical Paper requires any vertical facility manufacturing both fabric and finished products on the same site to track and report energy and water consumption separately by facility type. [S24] Higg FEM 4.0 also requires separate tracking of domestic versus production water and energy, with normalised baselines locked to each facility type's annual-volume unit of measure. [S24]

This rule directly governs industrial planning in Cameroon, whether for third-party integrated projects in the evidence register, such as Camtext SA (US$300 million, or 180 billion XAF, announced on 12 November 2025 for 12,000 tonnes a year with optimal capacity around 2033) [R09] [R10] or the announced SODECOTON-CICAM industrial pole targeted by 2030, [R08] or for GFT's phased garment-led programme. Third-party announcements for Camtext SA, SODECOTON and CICAM are sector context, not GFT engagements. [R08] [R09] [R10] Every site ledger must separate five sub-boundaries:

1. **Upstream dry fabric formation (spinning, knitting, weaving):** Denominator in accepted kilograms of grey yarn or fabric (kg), tracking motor electricity and humidification water. [S02] [S16] [S24]

2. **Wet processing (pretreatment, dyeing, printing, washing, drying, finishing):** Denominator in accepted kilograms of finished fabric (`kg`), tracking softened water, steam, fuel, electricity and chemicals per batch. [S02] [S04] [S16] [S24]
3. **Dry garment assembly (cutting, sewing, pressing, packing):** Denominator in accepted garments (`pieces`) and net mass (`kg`), metering sewing electricity, pressing steam and compressed air. [S24] [S28] [S30]
4. **Wet garment finishing (garment washing, dyeing, tumble drying):** Denominator in accepted wet-finished pieces (`pieces`) and mass (`kg`), isolated from dry sewing lines. [S07] [S24]
5. **Domestic and site auxiliaries (sanitation, canteen, clinics, external lighting):** Tracked in absolute cubic metres and kilowatt hours, never folded into process ratios. [S24] [S0201]

2.9 SHARED UTILITIES REQUIRE PHYSICAL ALLOCATION DRIVERS AND AN EXPLICIT UNALLOCATED RESIDUAL

When departments share central boilers, compressors or water-softening plants without 100 percent submetering, allocation rules determine whether ratios remain auditable. [S04] [S28] [S30] US Department of Energy (`DOE`) baselining guidance ranks direct submetering first, followed by a physical "standard unit of output" weighted by sub-process intensity, or physical mass and area, because energy correlates far better with mass or area than with revenue or labour hours. [S0201] Financial denominators such as revenue sit at the bottom of DOE's hierarchy (and are barred in DOE's ISO 50001-linked Superior Energy Performance programme) because price and margin shifts alter turnover without physical change. [S0201] Where financial screening is ever used, nominal revenue must be deflated by a price index, [S0201] and CFA franc (`XAF`) figures must state the euro peg (`655.957 XAF per euro`) and US dollar rate. [R32]

To prevent allocation from hiding leaks, GFT enforces a monthly utility conservation balance for every resource `u`: `U_main,u = sum(U_sub,u,p) + sum(A_u,k) + R_unalloc,u`, where main-meter intake equals submetered uses plus physically allocated shared loads plus an explicit unallocated residual `R_unalloc,u`. [S18] [S24] [S0201] Keeping `R_unalloc,u` visible ensures a broken submeter or pipe leak is never misread as process efficiency. [S04] [S18] [S24] GFT's operational KPI dictionary in **Exhibit 8**, p. 34 derives its structure from ISO 50001, [S18] Higg FEM 4.0, [S24] textile SEC benchmarking [S29] and DOE baselining guidance. [S0201]

EXHIBIT 08 / DERIVED GOVERNANCE SPECIFICATION

A KPI dictionary makes every ratio reproducible

KPI name	Unit	Numerator boundary	Denominator and release rule	Normalisation variables	Owner and cadence
Wet-process water intensity	L / accepted kg	Softened + raw water to preparation, dyeing, rinsing, finishing + re-dyes	Conditioned kg of fabric passing colour, fastness and physical release	Fibre, GSM, shade depth, machine route, batch fill ratio	Dyehouse manager; batch and weekly
Wet-process thermal intensity	MJ / accepted kg	Boiler fuel + steam enthalpy delivered to wet ranges, dryers and stenters	Conditioned kg of accepted finished fabric released to cutting or packing	Entry moisture, stenter passes, fabric GSM, batch volume	Utilities engineer; daily and monthly
Dyehouse electricity intensity	kWh / accepted kg	Submetered pumps, circulation drives, stenter fans, ETP + allocated air	Conditioned kg of accepted dyed and finished fabric; zero credit for scrap	Monthly volume, machine utilisation, treatment train load	Utilities engineer; weekly and monthly
CMT garment electricity intensity	kWh / accepted piece	Submetered cutting, sewing, pressing, lighting, HVAC + compressed air	Accepted garments passing final AQL inspection (first-pass + repaired pass)	Style family, standard allowed minutes, line utilisation, CDDs	Garment plant manager; shift and weekly
Garment wet-wash intensity	L / accepted piece	Fresh + recycled water entering garment-washing machines, rinses, hydro	Accepted wet-finished garments released to packing after shade/hand check	Garment mass (kg/piece), wash recipe, liquor ratio, load share	Finishing supervisor; batch and weekly
Site utility residual share	% of main meter	Main meter intake minus sum of process and domestic submeters	Total calibrated main-meter water (m3) or electricity (kWh) over period	Meter coverage percentage, calibration status, leak audit log	Sustainability lead; monthly reconciliation

DERIVED [S18] [S24] [S29] [S0201] Derived by GFT from ISO 50001 indicator governance (S18), Higg FEM 4.0 facility separation (S24), specific-energy textile benchmarking (S29) and US DOE baselining hierarchy (S0201).

As shown in **Exhibit 8**, p. 34, each KPI binds unit, numerator boundary, quality-gated denominator, normalisation variables and owner cadence. [S18] [S24] [S29] [S0201] While **Exhibit 8**, p. 34 standardises data capture, valid comparison across time still requires statistical normalisation for product mix and volume.

2.10

Product mix requires normalisation before comparison

Comparing raw resource ratios across quarters without checking product mix or production volume violates engineering causality. [S02] [S29] [S0201] Resource demand depends on intrinsic product attributes (fibre, construction, GSM and shade depth) and extrinsic operating conditions (batch fill, plant utilisation and ambient weather). [S02] [S04] [S29] [S0201]

2.11 FIBRE COMPOSITION, SHADE DEPTH, MACHINE ROUTE AND LOT SIZE SHIFT BASELINE DEMAND

The European BAT Reference Document [S02] and empirical mill surveys [S04] show why product mix drives water, chemical and thermal demand. In the 2023 PLOS survey of 18 Bangladeshi wet-processing factories, [S04] specific water consumption ranged tenfold from 28 L/kg in denim dyeing to 285 L/kg in a knit-composite mill (Factory C), where 72 percent of dyed fabric was deep shade, against a sample mean of 47 percent deep shades (above 3 percent dye depth), 27 percent medium shades (1 to 3 percent) and 26 percent white or light shades (below 1 percent). [S04]

In reactive dyeing of cotton, deep shades require up to 80 g/L of electrolyte salt, more alkali and multiple hot rinses to remove unfixed dye (10 to 40 percent unfixed dye loss), driving chemical consumption across the 18 mills from 152 g/kg to 705 g/kg (mean 449 g/kg). [S04] [S31] Similarly, continuous woven ranges differ from batch knit jets, [S02] [S16] and under-loading a batch machine rated for an illustrative 500 kg with a 250 kg lot inflates effective liquor ratio and bath-dosed salt per kilogram. [S02] [S04]

2.12 SPECIFIC ENERGY AND WATER INDICATORS REQUIRE REGRESSION TESTING AGAINST PRODUCTION VOLUME AND MIX

Simple Specific Energy Consumption (SEC) ratios also vary with throughput because every plant carries fixed base loads. [S29] [S0201] A 2021 Riga Technical University study [S29] analysed 36 monthly records (2017 to 2019) across 10 summed textile product categories measured in kilometres (km):

1. **Specific electricity (MWh/km) versus volume:** Across 35 records (March 2019 missing), annual mean SEC fell from 0.123 MWh/km in 2017 (0.113 to 0.135 MWh/km) to 0.096 MWh/km in 2018 (0.085 to 0.114 MWh/km) and 0.079 MWh/km in 2019 (0.054 to 0.140 MWh/km), with linear regression against volume yielding R2 = 0.6404 as higher volume reduced downtime. [S29]
2. **Specific natural gas (m3/km) versus volume:** Across 36 records (0.008 to 0.048 m3/km), regression against volume yielded only R2 = 0.1835 because winter space heating (40 percent of cold-climate textile energy cited) was pooled with process heat, and identical monthly output numbers in March to June and September to October indicated planning figures had replaced actual output. [S29]

This finding is critical for Cameroon, where a July 2023 report on incumbent CICAM recorded utilisation of 33.7 percent at Garoua, 48.9 percent at CICAM 1 and 10.83 percent at CICAM 2, costing about CFAF 2 billion in 2020 (sector context, not a

GFT result). [R12] When utilisation fluctuates or power outages occur, [S25] fixed base-loads distort simple ratios. [S17] [S28] [S29] GFT therefore applies US DOE baselining rules: [S0201]

- **Linear regression (`E_hat_u`):** Over at least `12 months`, fit `E_hat_u = E_0,u + sum(b_u,f * Q_acc,f) + (c_u * W_m)` across accepted output by shade family (`Q_acc,f`) and weather (`W_m`), separating fixed baseload `E_0,u` from marginal intensity `b_u,f`. [S29] [S0201]
- **Statistical validity gates:** Require variable p-values below `0.10`, at least one below `0.05`, and rank models by adjusted `R2`. [S0201]
- **Product-family stratification:** Where product mix is too diverse for one equation, stratify by fibre, route and shade band (below `1 percent`, `1 to 3 percent`, above `3 percent`), [S04] or apply a DOE intensity-weighted "standard unit of output." [S02] [S04] [S0201]

2.13

Mass balances expose missing meters and impossible savings

Even a normalised ratio fails if numerator meters are incomplete or bypassed. [S04] [S18] Every litre of water entering a site leaves as treated effluent, bypass, dryer evaporation, product moisture, domestic sewage or sludge moisture, [S04] [S05] [S17] and every megajoule of fuel and electricity leaves as process heat, mechanical work or thermal loss. [S16] [S17]

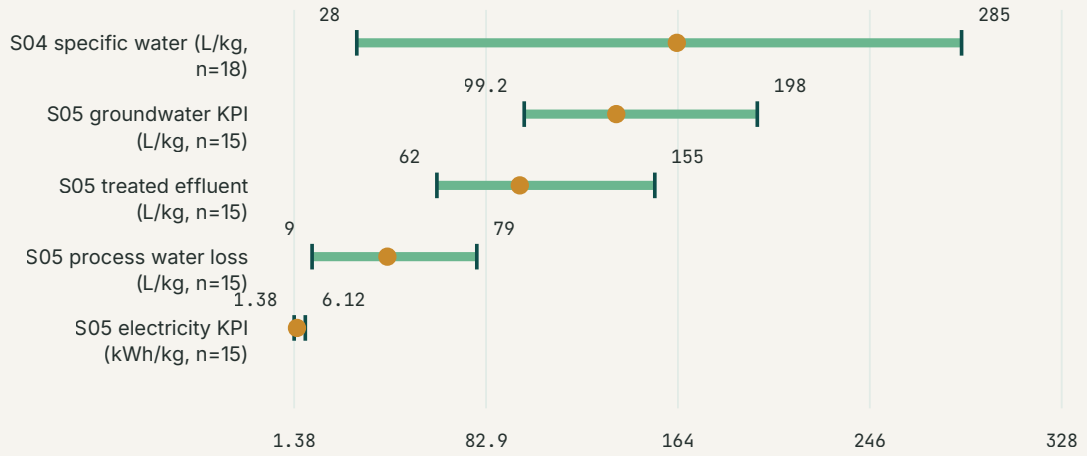
2.14 RECONCILING INTAKE, DYEHOUSE SOFTENED WATER, EFFLUENT AND PROCESS LOSS CATCHES PHANTOM REDUCTIONS

Two Bangladesh wet-processing studies demonstrate how site water balances expose both inter-mill spread and meter gaps. [S04] [S05] In the 18-factory PLOS survey, [S04] groundwater intake averaged `164 L/kg` (`SD 81.8`, range `28 to 285 L/kg`), softened dyehouse water averaged `136 L/kg` (`SD 70.6`, `68 to 100 percent` of groundwater), and wastewater averaged `119 L/kg` (`SD 73.0`). However, wastewater reaching treatment ranged from `50 percent` to `105 percent` of dyehouse water across individual mills, exposing unmeasured leaks and bypasses at the low end and stormwater infiltration at the high end. [S04]

In the 15-mill MDPI baseline study (2019 data averaging `7,602.88 tonnes` of dyed fabric, `17,689.43 MWh` of electricity, `961.26 million litres` of groundwater and `640.24 million litres` of treated effluent per mill), [S05] groundwater intensity spanned `99.15 to 198.20 L/kg` (mean `138.26 L/kg`), treated effluent spanned `62.04 to 154.64 L/kg` (mean `97.27 L/kg`), process water loss spanned `9.0 to 79.0 L/kg` (mean `41.0 L/kg`), and electricity spanned `1.38 to 6.12 kWh/kg` (mean `2.58 kWh/kg`), while World Bank and IFC estimates reached `250 to 300 L/kg`. [S05] [S08] Both empirical distributions are plotted separately in **Exhibit 9**, `p. 37`. [S04] [S05]

EXHIBIT 09 / L/KG OR KWH/KG (SEE LABELS)

Observed mill intensity shows why site baselines matter



SOURCED [S04] [S05] Sourced from two separate Bangladesh empirical studies: 18 wet-processing factories in S04 (2023) and 15 dyeing mills in S05 (2022, 2019 data). Displayed as separate studies with no pooled average.

The ranges in **Exhibit 9**, p. 37 (28.0 to 285.0 L/kg in [^S04]; 99.15 to 198.20 L/kg and 1.38 to 6.12 kWh/kg in [^S05]) prove why no external average can replace a metered Cameroon baseline, and why the 9.0 to 79.0 L/kg process loss gap requires both intake and discharge meters. [S04] [S05]

2.15 FUEL, STEAM AND ELECTRICAL BALANCES PREVENT BOUNDARY SHIFTING INSIDE THE UTILITY HOUSE

The US DOE *Improving Process Heating System Performance* sourcebook [S17] requires a systems review across fuel input, steam generation, distribution and process heat transfer. Because wet processing accounts for 50 percent of composite-plant thermal demand, [S16] metering electricity without fuel and steam allows a mill to shift heating duties between electric dryers and fuel boilers while claiming a false reduction. [S16] [S17] GFT requires monthly closure of both the primary fuel-and-electricity balance (MJ and kWh) and the boiler steam-and-condensate balance (kg steam). [S17] [S18] [S0201]

UNRECONCILED UTILITY BILLS AND PLANNING DENOMINATORS INVALIDATE SAVING CLAIMS

GFT's audit gate blocks baseline approval when any of five empirical failure modes appears: [S04] [S29]

1. **Planning volumes used as output:** Identical monthly volumes in March to June and September to October exposed planning numbers in the Latvian study; [S29] GFT requires physical warehouse-release reconciliation.
2. **Impossible effluent-to-intake ratios:** Effluent outside `50 to 105 percent` of dyehouse water exposed bypasses or stormwater intrusion in Bangladesh; [S04] GFT flags any mass-balance residual exceeding an illustrative `10 percent` tolerance.
3. **Unaligned meter outages:** Missing March 2019 electricity in the Latvian study [S29] shows why output from un-metered shifts (e.g., a `3-shift` illustrative outage) must be excluded from both numerator and denominator. [S18]
4. **Omitted water-plant reject streams:** Softening (`68 to 100 percent` of groundwater) [S04] and reverse osmosis generate brine and backwash that must stay in the site balance. [S24]
5. **Unseparated seasonal loads:** Pooling space conditioning with process heat (`R2 = 0.1835`) [S29] mistakes weather shifts for efficiency.

2.16

Baseline changes need documented rules

A baseline is the reference against which performance is judged. [S18] [S0201] Informal changes make improvement unfalsifiable, while freezing an obsolete boundary distorts engineering reality. [S18] [S23] [S24] [S0201]

2.17 STRUCTURAL BOUNDARY CHANGES AND METHODOLOGY UPDATES REQUIRE FORMAL BASELINE VERSIONING

ISO 50001:2018, [S18] Higg FEM 4.0 [S24] and US DOE guidance [S0201] separate routine normalisation (forecasting, backcasting or chaining across volume and weather, with Higg baselines capped at `5 years` and DOE SEP baselines audited every `3 years`) [S24] [S0201] from non-routine structural restatements triggered by three events:

- **Boundary changes reaching the 5 percent materiality threshold:** Adding, acquiring, closing or outsourcing a process stage representing `5 percent` or more of baseline use requires adjusting the baseline before computing savings, preventing boundary shedding from masquerading as efficiency. [S24] [S0201]
- **Product-mix regime shift invalidating regression statistics:** When a new product regime breaks model validity (`p-values` or `R2`), DOE rules establish an "intermediate baseline year" after `12 months` of new data, banking prior verified improvements. [S0201]
- **Meter and denominator upgrades:** Moving from bills to batch submeters or from gross weight to accepted weight requires backcast restatement or a versioned dual-display transition year. [S18] [S24] [S0201]

2.18 GFT'S GOVERNANCE CONTRACT LOCKS DENOMINATOR DEFINITIONS ACROSS OPERATIONS AND PRODUCT REPORTING

Textile Exchange's August 2025 guidance *Ensuring Integrity in the Use of Life Cycle Assessment Data* [S23] recommends using LCA data only with full understanding of assumptions, methods and use cases. A site ratio (`L/accepted kg`) is a gate-to-gate operational metric, [S10] [S18] [S30] not a full cradle-to-grave product footprint under ISO 14040, [S20] ISO 14046, [S11] the EU Ecodesign for Sustainable Products Regulation (`ESPR`, Regulation (EU) 2024/1781) [S21] or the EU Product Environmental Footprint (`PEF`) rules, [S22] which also cover cotton farming (`green`, `blue` and `dilution` water), [S09] [S10] ginning, transport and consumer use. Any factory ratio exported to a product inventory must carry its baseline version, meter coverage, allocation driver, `RFT` rate and residual share. [S18] [S23] [S24]

GFT NOTE

For GFT's Cameroon textile programme, denominator governance connects directly to the `footprint`, `kpi-cascade` and `unit-economics` tools:

1. **Lock the denominator in the batch schema:** Compute `L/kg`, `kWh/kg`, `MJ/piece` and `L/piece` exclusively against `accepted_qty_released`, displaying `gross_qty_loaded`, `reprocessed_qty` and `rejected_qty` beside it. [S37]
2. **Tag roll GSM and marker yield at cutting:** Log conditioned roll `GSM`, cuttable width and marker yield (`%`) on every cutting order [S0202] to calculate actual required fabric per accepted garment (`m_fab,req`).
3. **Enforce Higg FEM 4.0 separation from day one:** Submeter fabric wet processing, dry garment assembly, wet garment washing and domestic auxiliaries separately, [S24] reporting the main-meter residual (`R_unalloc`) monthly. [S18]
4. **Version baseline restatements immutably:** Require formal sign-off of the KPI dictionary (**Exhibit 8**, `p. 34`) under ISO 50001 cadence [S18] and preserve legacy records whenever a `5 percent` scope adjustment occurs. [S0201]

By locking the denominator to accepted output, grounding fabric-to-garment conversion in physical measurements, separating facility subtotals with an explicit residual, normalising for product mix and volume, closing mass and energy balances, and versioning baseline rules, a textile factory makes efficiency falsifiable. [S04] [S18] [S24] [S29] [S37] [S0201] The next chapter examines the water numerator, showing why a litre matters according to where and when it is taken.

Efficiency begins when the denominator counts only the product the customer can accept.

CHAPTER SOURCE NOTES

S24 Sustainable Apparel Coalition. 2022.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

S18 International Organization for Standardization. 2018.

S37 Emerald Publishing Limited. 2019.

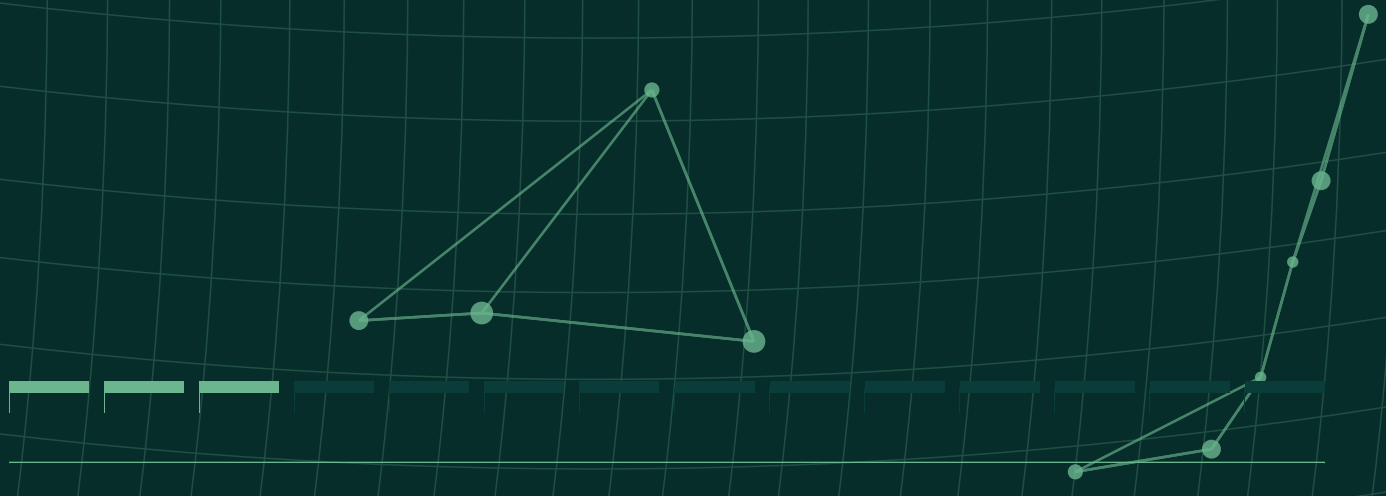
S0201 United States Department of Energy, Better Buildings, Better Plants Program. 2015-01.
S04 PLOS Sustainability and Transformation. 2023-07-31.
R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.
R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.
S01 International Finance Corporation, World Bank Group. 2007-04-30.
S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.
S31 Springer Nature, Scientific Reports. 2022-12-26.
S02 European Commission Joint Research Centre. 2023.
S05 MDPI, Textiles. 2022-09-28.
S07 United Nations Industrial Development Organization. 2018-03-22.
S30 Springer Nature, Energy Efficiency. 2024-12-03.
S0202 PLOS One. 2025-05-15.
R26 Statista. Publication date unrecorded; inherited source-text check.
S16 MDPI, Energies. 2022-11-25.
R09 Ecofin Agency. Publication date unrecorded; inherited source-text check.
R10 Ecofin Agency. Publication date unrecorded; inherited source-text check.
R08 Business in Cameroon. Publication date unrecorded; inherited source-text check.
S28 United States Department of Energy and Compressed Air Challenge. 2003.
R32 Wise; XE. Publication date unrecorded; inherited source-text check.
R12 Business in Cameroon. Publication date unrecorded; inherited source-text check.
S25 World Bank. 2025-06-25.
S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.
S08 2030 Water Resources Group, World Bank. 2015.
S23 Textile Exchange. 2025-08-07.
S10 Earthscan, for Water Footprint Network. 2011.
S20 International Organization for Standardization. 2006.
S11 International Organization for Standardization. 2014-07-24.
S21 European Parliament and Council. 2024-06-13.
S22 European Commission, Directorate-General for Environment. 2025-06-25.
S09 Elsevier, Ecological Economics. 2006.

03

PART I: DEFINE THE UNIT BEFORE REDUCING IT / WATER IN CONTEXT

A litre matters according to where and when it is taken

Volumetric accounting becomes decision-ready only when source, catchment, season, quality and discharge are attached to each litre.



CHAPTER 03
DECISION TEST

Volumetric accounting becomes decision-ready only when source, catchment, season, quality and discharge are attached to each litre.

A factory water ratio in litres per accepted kilogram of fabric or per accepted garment is a necessary operational control, but volume alone cannot establish environmental safety or industrial supply security. Two textile mills that each withdraw an illustrative 100 litres of freshwater per accepted kilogram face fundamentally different engineering, financial and regulatory risks if one draws from a seasonally recharged river with tertiary effluent treatment while the other pumps a declining coastal aquifer and discharges untreated salt and reactive-dye residuals into an unmonitored urban drain. [S01] [S14] For Green Future Tech Limited (GFT), Hong Kong SAR, and its three-part Cameroon textile programme prepared on 31 January 2024 with sources refreshed in 2026, water accounting must attach five attributes to every metered cubic metre: the hydrological category of the water, the assessment boundary of the metric, the local catchment and seasonal reliability of the intake, the chemical quality of the effluent, and the mass and energy balances of any reuse loop. [S06] [S10] [S11] Expanding domestic cotton processing in Cameroon from the inherited baseline of about 5 percent processed locally against 95 percent exported raw toward the national target of 50 percent by 2030 moves wet-processing water intake and discharge onto domestic catchments. [R06] [R07] This chapter establishes the contextual rules required to govern those flows before capital is committed; it provides an engineering and management framework and does not constitute investment, legal or tax advice, nor does it replace a statutory environmental impact assessment or hydrogeological survey.

3.1

Water categories prevent a single-volume misunderstanding

Published statements about the water demand of cotton textiles routinely mix agricultural soil moisture, irrigation withdrawals, factory process intakes and theoretical pollution-dilution volumes into a single headline figure. When those distinct physical and analytical quantities are collapsed into one number, plant engineers and investment sponsors cannot tell whether a proposed intervention saves piped municipal water in the dyehouse, reduces irrigation depletion on the farm, or lowers chemical oxygen demand at the outfall. [S09] [S10] The first rule of GFT's water ledger is therefore taxonomic: every volumetric figure must carry a strict category label that defines both where the water originates and how it leaves the boundary under study.

In supply-chain water accounting, the Water Footprint Assessment Manual published for the Water Footprint Network defines the water footprint of a product as the total volume of freshwater used to produce that item measured across the entire supply chain. [S10] Applying that supply-chain methodology to global cotton consumption, Chapagain et al. demonstrated that cotton product impacts span the countries where cotton is grown and the locations where yarn, fabric and garments are processed, and separated the account into three non-interchangeable components: green water, blue water and dilution (or grey) water. [S09] [S10] Green water designates rainwater stored in the soil root zone that is evapotranspired by the cotton crop during agricultural growth. [S09] [S10] Blue water designates surface water or groundwater withdrawn for irrigation or industrial processing that is evaporated, incorporated into the product, or not returned to the same catchment within the same period. [S09] [S10] Grey water (referred to as dilution water in earlier cotton studies) does not represent a physical

volume pumped through a pipe; instead, it represents the theoretical volume of ambient freshwater required to assimilate a discharged pollutant load so that receiving water quality remains within agreed ambient standards. [S09] [S10]

Treating green, blue and grey water as additive equivalents inside a factory dashboard distorts engineering decisions. In rain-fed cotton zones such as northern Cameroon, where SODECOTON supports more than 220,000 cotton producers and operates nine ginning plants and two oil mills according to the inherited evidence register, crop growth relies predominantly on seasonal green water in the soil profile rather than irrigated blue water. [R03] [S09] Once baled lint enters a spinning, weaving, wet-processing or garment-washing facility, however, process demand shifts entirely to withdrawn blue water and generates concentrated liquid effluent that creates a downstream assimilation burden. [S01] [S03] A literature review by VTT Technical Research Centre of Finland estimates that textile wet processes consume approximately 60 to 90 percent of the total water used within textile manufacturing facilities, making preparation, dyeing, rinsing and finishing the primary industrial blue-water boundary. [S03] The International Finance Corporation (IFC) Environmental, Health, and Safety Guidelines for Textile Manufacturing likewise connect freshwater intake directly to wastewater and sludge generation and to the thermal energy required to heat process baths. [S01]

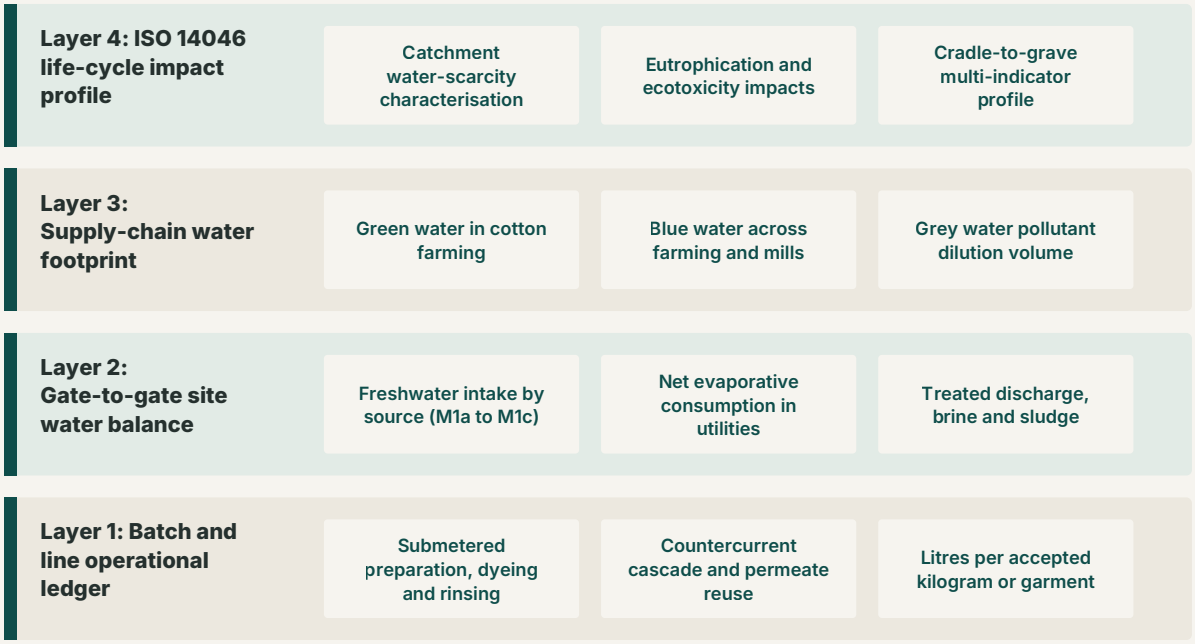
Furthermore, the Water Footprint Assessment Manual warns that adding the water footprints of intermediate and final products across overlapping stages results in double counting, because the supply-chain footprint of finished cotton fabric already embeds the agricultural water footprint of harvested seed cotton. [S10] At the factory gate, an operational key performance indicator (KPI) should never be labelled a "product water footprint" unless the scope explicitly includes upstream agricultural green and blue water and follows a documented supply-chain method. [S10] [S11] Instead, factory records should separate four physical flows and one analytical indicator, as structured in **Exhibit 10**, p. 44:

1. **Freshwater intake (W_{in}):** The metered volume of water entering the facility boundary from municipal networks, surface-water intakes, on-site boreholes, harvested rainwater or tankered deliveries, reported in litres or cubic metres per period and per accepted unit of output. [S04] [S0302]
2. **Recycled process water (W_{rec}):** Treated effluent or segregated countercurrent rinse water returned to a defined process duty inside the facility after passing a fit-for-purpose quality gate. [S01] [S06]
3. **Net site water consumption (W_{cons}):** The portion of freshwater intake that is evaporated in dryers, stenters, boilers and cooling towers, incorporated into shipped goods, or lost from the local catchment boundary rather than returned as liquid discharge. [S10] [S0302]
4. **Wastewater and residual outflow (W_{out}):** Liquid effluent discharged to a municipal sewer, shared industrial effluent treatment plant or receiving surface-water body, tracked alongside separated membrane concentrate and dewatered sludge. [S04] [S06] [S13]

5. **Pollutant mass load and theoretical dilution volume (L_{p} and W_{grey}):** The measured concentration and mass of chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total dissolved solids (TDS), total suspended solids (TSS), heavy metals and restricted chemical residuals leaving the site, which can be converted into a grey-water assimilation indicator only when an explicit ambient receiving standard and background concentration are stated. [S10] [S33]

EXHIBIT 10 /

Factory water metrics sit inside, but do not replace, life-cycle accounting



SOURCED [S09] [S10] [S11] Nested water-accounting boundaries structured from Chapagain et al. (S09), the Water Footprint Assessment Manual (S10) and ISO 14046:2014 (S11). Operational factory KPIs measure gate-to-gate physical flows, whereas supply-chain and ISO 14046 accounts evaluate multi-stage volumes and characterised environmental impacts.

As **Exhibit 10**, p. 44 illustrates, each layer answers a distinct engineering or policy question. Layer 1 governs shift-level process control on the factory floor, linking machine fills and rinse sequences to accepted output. Layer 2 reconciles submeters to the facility's main intake and outfall meters over a weekly or monthly utility close. Layer 3 connects the factory to its agricultural and upstream manufacturing supply chain under Water Footprint Network accounting rules. [S10] Layer 4 applies life-cycle impact characterisation under ISO 14046:2014. [S11] While **Exhibit 10**, p. 44 maps the conceptual nesting of these four boundaries, it cannot supply a conversion factor between Layer 1 and Layer 4: a low value in Layer 1 does not prove a low environmental impact in Layer 4 unless catchment scarcity and effluent chemistry are independently verified.

METHOD

Boundary separation between metered pipe flows and grey-water assimilation

To prevent unit corruption in the GFT resource ledger, physical water balances and pollutant assimilation indicators are calculated in separate equations. [S10] [S0302]

1. **Gate-to-gate physical mass balance (cubic metres per batch or period):** $W_{\text{in}} + W_{\text{rec}} = W_{\text{proc}} + W_{\text{util}} + W_{\text{san}} $ and $W_{\text{in}} = W_{\text{cons}} + W_{\text{out,eff}} + W_{\text{out,conc}} + W_{\text{out,sludge}} + \varepsilon_{\text{unalloc}}$, where W_{in} is total freshwater intake across all external sources, W_{rec} is internally recycled water re-entering process or utility headers, W_{proc} is total process water (preparation, dyeing, rinsing, finishing, garment washing), W_{util} is utility water (boiler make-up, cooling, regeneration), W_{san} is domestic and sanitation water, W_{cons} is net evaporative and incorporated consumption, $W_{\text{out,eff}}$ is discharged liquid effluent, $W_{\text{out,conc}}$ is rejected brine or concentrate, $W_{\text{out,sludge}}$ is water bound in removed sludge, and $\varepsilon_{\text{unalloc}}$ is the unallocated meter residual. [S04] [S06] [S0302]
2. **Operational freshwater intensity (litres per accepted unit):** $I_{\text{fw}} = (1000 \times W_{\text{in}}) / Q_{\text{acc}}$, where Q_{acc} is accepted output released to the next stage (in kilograms of fabric or count of garments), retaining all water consumed by rejected or reprocessed lots inside W_{in}. [S24]
3. **Theoretical grey-water assimilation volume (cubic metres per period, reported separately):** $W_{\text{grey},p} = L_p / (C_{\text{max},p} - C_{\text{nat},p}) = (W_{\text{out,eff}} \times C_{\text{eff},p} - W_{\text{in,surf}} \times C_{\text{act},p}) / (C_{\text{max},p} - C_{\text{nat},p})$ following the Water Footprint Assessment Manual, where L_p is the net pollutant mass load added to the receiving water body for parameter p, $C_{\text{eff},p}$ is the pollutant concentration in discharged effluent, $C_{\text{act},p}$ is the actual concentration in water abstracted from the same surface source ($W_{\text{in,surf}}$), $C_{\text{max},p}$ is the maximum permissible ambient concentration in the receiving water body, and $C_{\text{nat},p}$ is the natural background concentration. [S10] Because $W_{\text{grey},p}$ is a regulatory and ecological assimilation ratio rather than a withdrawn flow, it must never be added to W_{in} in a factory utility balance. [S10]

3.2

A site KPI and an ISO water footprint serve different decisions

Industrial sponsors and sustainability teams frequently ask whether their factory water ledger complies with international water-footprint standards. Answering that question requires separating operational performance tracking from life-cycle assessment. Published on 24 July 2014, ISO 14046:2014 specifies principles, requirements and guidelines for the water-footprint assessment of products, processes and organisations based on life-cycle assessment (LCA) in accordance with ISO 14040 and ISO 14044. [S11] Under ISO 14046:2014, a water-footprint assessment is not a simple sum of litres read from a flowmeter; it is a formal LCA study that

compiles a water-related life-cycle inventory across defined system boundaries and applies impact assessment methods to evaluate potential environmental impacts associated with water quantity and water quality. [S11]

The distinction between a daily site KPI and an ISO 14046:2014 water-footprint profile is operational as well as methodological. On the factory floor, a dyehouse manager or garment-washing supervisor needs an immediate, unambiguous physical signal: how many litres of freshwater and how many litres of softened process liquor were consumed today to produce each accepted kilogram of reactive-dyed jersey or each accepted pair of washed trousers, and how did that ratio compare against the product family's baseline? [S05] [S24] That operational KPI must be available at shift or batch closure, must use unweighted physical litres so that mass balances reconcile to tank levels and flowmeters, and must isolate the facility's own gate-to-gate boundary. [S18] [S24]

In contrast, an ISO 14046:2014 assessment is designed for strategic product comparisons, catchment-sensitive siting studies, life-cycle Hotspot identification and external environmental disclosures. [S11] Because ISO 14046:2014 is impact-based, a cubic metre of water consumed in an arid basin with severe aquifer overdraft receives a different scarcity-weighted characterisation factor from a cubic metre withdrawn in a humid basin with abundant perennial runoff, and an effluent stream containing persistent salts or nutrients is characterised across water-degradation impact categories such as freshwater eutrophication or ecotoxicity. [S11] Moreover, Textile Exchange's 2025 report on integrity in the use of LCA data emphasises that LCA datasets should be used only when decision-makers understand their underlying assumptions, methodological rules, allocation choices and geographic or temporal limitations. [S23] Importing a generic global secondary LCA factor for "cotton dyeing" into a Cameroon project feasibility model would hide the very variables that engineering design is meant to control: machine liquor ratio, countercurrent washing efficiency, right-first-time shade release and local effluent treatment. [S02] [S23]

Facility-level reporting frameworks reinforce this boundary discipline. The Higg Facility Environmental Module (FEM) 4.0 Technical Paper published by the Sustainable Apparel Coalition requires any integrated facility that manufactures both fabric and finished garments on the same site to track and report its water and energy consumption separately by facility type. [S24] Without that separation, a plant combining a high-volume wet dyehouse (measured in litres per kilogram of fabric) with a cut-make-trim sewing hall (where water is used primarily for steam pressing, evaporative cooling and worker sanitation, measured per piece) would produce a blended ratio that neither benchmark tables nor line managers can interpret. [S03] [S24]

For GFT's Cameroon textile programme, keeping the site KPI and the ISO 14046:2014 boundary distinct prevents two opposite management failures. First, it prevents a garment-assembly operation that outsources wet processing to a regional partner from claiming a "low water footprint" merely because its own sewing floor uses little water; under ISO 14046:2014 and supply-chain accounting, the partner dyehouse's withdrawals and discharges remain inside the product's life-cycle boundary. [S10] [S11] Second, it ensures that plant engineers do not wait for a multi-year cradle-to-grave LCA before installing electromagnetic flowmeters on dyehouse headers, fixing leaking pneumatic drain valves and enforcing batch-level liquor-ratio discipline. [S01] [S02] In

GFT's architecture, the batch-level site ledger supplies the primary foreground life-cycle inventory data that a later ISO 14046:2014 or Product Environmental Footprint (PEF) study requires, while maintaining a clean, unweighted volumetric ledger for daily factory control. [S11] [S23]

3.3

National water stress cannot certify factory water security

When international investors screen African manufacturing locations, they often consult country-level hydrological tables and conclude that humid or sub-humid nations in Central Africa face negligible water risk. The 2024 mid-term progress report on Sustainable Development Goal (SDG) Indicator 6.4.2, published jointly by the Food and Agriculture Organization of the United Nations (FAO) and UN-Water, defines water stress as the ratio of total freshwater withdrawn by all major economic sectors (agriculture, industry and municipalities) to total renewable freshwater resources after deducting environmental flow requirements (EFR). [S12] At the global scale, the report documents that water stress increased by 2.8 percentage points since 2015, reaching 18.6 percent in 2021. [S12] In Annex 1 of the same 2024 FAO and UN-Water report, Cameroon's national water-stress level is recorded at 1.56 percent in 2015 and 1.56 percent in 2021, representing a 0.00 percentage-point change and placing the country as a whole well below the 25 percent threshold that demarcates the boundary between "no stress" and "low stress". [S12]

Using that 1.56 percent national figure to declare a Cameroonian textile site immune to water scarcity or supply disruption would be a severe engineering error. The FAO and UN-Water report itself explicitly warns that national water-stress values can hide substantial subnational variations at the river-basin level, noting that countries with safe national aggregates routinely contain individual river basins experiencing acute stress. [S12] National annual averages pool runoff across entirely distinct hydroclimatic zones and across twelve calendar months. In Cameroon, a national denominator combines the equatorial coastal and southern forest river systems with the Sudano-Sahelian northern cotton belt around Garoua and Maroua, where rainfall is highly seasonal and dry-season surface flows contract sharply. Even within a high-runoff coastal basin, annual river discharge does not equate to treated, pressurized industrial water at a factory boundary.

The contrast between macro-level hydrological abundance and local infrastructure reality is starkly illustrated in Douala, Cameroon's primary port and industrial hub. In a feature report dated 26 September 2025, the World Health Organization (WHO) documented that only 42 percent of households in Douala have reliable access to potable water within 500 metres of a tap, and that out of an estimated 250 kilometres of urban drainage required across the city, only 50 kilometres have been constructed. [S15] The same 2025 WHO account notes that inadequate water access, sanitation and drainage contribute directly to waterborne diseases including malaria, typhoid and cholera, with cholera having become endemic in the city since October 2021. [S15]

Both numbers require strict methodological quarantine before they enter an industrial feasibility study, as summarised in **Exhibit 11**, p. 48. Cameroon's 1.56 percent SDG 6.4.2 value measures national annual withdrawals relative to national renewable runoff less environmental flows; it says nothing about municipal treatment capacity, distribution-pipe leakage, dry-season aquifer drawdown or power-outage pumping interruptions at an industrial estate. [S12] Conversely, the WHO figure of 42 percent household potable-water access within 500 metres of a tap is a domestic public-health and community-access metric; it cannot be converted into an uptime percentage for a high-pressure industrial water main or a deep factory borehole. [S15] What the juxtaposition proves is that hydrological resource availability in a river basin and engineered supply reliability at a tap or manifold are governed by entirely different physical systems.

EXHIBIT 11 /

National abundance and local reliability are different facts

1.56%

Cameroon national water stress (2021)

SDG 6.4.2 withdrawal share of renewable resources after EFR; unchanged from 2015 (S12 Annex 1)

18.6%

Global water stress level (2021)

Global SDG 6.4.2 aggregate across reporting states, up 2.8 percentage points since 2015 (S12)

42%

Douala household tap access (2025)

Share of Douala households with reliable potable water within 500 m of a tap (S15)

50 / 250 km

Douala drainage built vs needed (2025)

Constructed urban drainage network relative to estimated 250 km city requirement (S15)

SOURCED [S12] [S15] Cameroon national water stress (1.56 percent in 2015 and 2021) and global water stress (18.6 percent in 2021) are transcribed from the 2024 FAO and UN-Water SDG Indicator 6.4.2 report and its Annex 1 (S12). Douala household reliable potable-water access (42 percent within 500 m of a tap) and constructed drainage (50 km of 250 km needed) are from the 2025 WHO account (S15). Neither indicator establishes industrial supply security at a factory site.

The comparative evidence from South Asian textile clusters reinforces the lesson of **Exhibit 11**, p. 48. In Annex 1 of the same 2024 FAO and UN-Water report, Bangladesh records a national water-stress level of just 5.72 percent in both 2015 and 2021, placing it in the same "no stress" national band (<25 percent) as

Cameroon. [S12] Yet empirical studies of Bangladesh's textile wet-processing zones document severe local groundwater stress because factories concentrate withdrawals in specific alluvial aquifers. In a 2023 survey of 18 textile wet-processing factories in Bangladesh published in PLOS Sustainability and Transformation, average specific groundwater consumption was 164 litres per kilogram of processed textile material (with a standard deviation of about 81.8 litres per kilogram), and the authors note that this intensive extraction is directly linked to regional groundwater depletion and wastewater pollution. [S04] Similarly, a 2022 study of 15 textile dyeing mills in Bangladesh published in MDPI Textiles recorded extracted groundwater KPIs ranging from a minimum of 99.15 litres per kilogram to a maximum of 198.20 litres per kilogram, with a sample average of 138.26 litres per kilogram. [S05] A national SDG 6.4.2 figure below 6 percent did not protect those industrial clusters from falling water tables.

In Cameroon, industrial textile planning spans both northern cotton-growing zones and southern coastal or peri-urban hubs. Public reporting in the inherited evidence register notes that the announced Camtext SA project (a US$300 million, or 180 billion XAF, integrated cotton-to-textile venture reported on 12 November 2025 involving Panafritex and Arise with SODECOTON, CNPS and Marlo) targets processing 12,000 tonnes a year with activities split between a Dibamba hub near Douala (projected at about 12,000 jobs) and Garoua in the North Region (projected at about 3,000 jobs), while the incumbent producer CICAM operated plants in Garoua and Douala whose July 2023 reported capacity utilisation stood at 33.7 percent at Garoua, 48.9 percent at CICAM 1 and 10.83 percent at CICAM 2. [R09] [R10] [R12] Those third-party announcements and historical utilisation figures describe sector context rather than GFT operations, but they highlight the two distinct hydrological environments any Cameroonian textile programme must evaluate:

- **Northern Sudano-Sahelian catchments (such as the Bénoué basin around Garoua):** Characterised by a pronounced dry season, high evaporative demand, and competing agricultural and municipal water uses, where dry-season low flows constrain both surface abstraction and the dilution capacity of receiving rivers. [S12] [S0301]
- **Littoral coastal and estuarine catchments (such as Douala and the Dibamba or Wouri basins):** Characterised by high annual rainfall and large river discharges, but also by shallow water tables, coastal flood and drainage bottlenecks (as reflected in the 50 kilometres of built drainage against 250 kilometres needed in Douala), saline intrusion risks in over-pumped coastal boreholes, and dense urban populations vulnerable to surface and groundwater contamination. [S15] [S0301]

WARNING

Constraint: National and municipal macro-indicators cannot substitute for site hydrogeology

No GFT feasibility model or site-selection dossier may cite Cameroon's 1.56 percent national water-stress figure as evidence that an industrial plot has adequate water supply, nor may it extrapolate Douala's 42 percent household potable-water access statistic as a numerical estimate of factory downtime. [S12] [S15] Resolving site water security requires four pre-investment engineering deliverables for the exact coordinates under evaluation: 1. A 24-month historical log (or stepped pumping test for boreholes) of available flow rate, static and dynamic water levels, and seasonal pressure variance across the dry and wet seasons. [S0302] 2. A raw-water laboratory profile covering hardness, alkalinity, iron, manganese, silica, conductivity, total dissolved solids, suspended solids and microbiological load across both wet-season runoff peaks and dry-season low-flow concentration peaks. [S02] [S0302] 3. Written verification of the municipal water utility's contracted delivery pressure, curtailment priority and tariff structure, alongside the site's power-backup architecture for intake and treatment pumps. [S25] [S0302] 4. A receiving-water assimilation study establishing dry-season 7-day or 30-day low flows, downstream community and potable intakes, and statutory effluent discharge limits. [S10] [S14] [S0302]

3.4

Source-to-discharge mapping reveals operational dependencies

To convert contextual water risk into an auditable factory control, a plant must map and meter its physical water network from every external intake point through storage and pretreatment to every process user, treatment unit and final discharge outfall. The International Water Stewardship Standard Version 2.0, published by the Alliance for Water Stewardship (AWS) on 22 March 2019, establishes that the fundamental spatial unit of water stewardship is the local river basin or catchment from which an organisation draws its water supply and to which it returns its discharges and wastewater. [S0302] Under AWS Step 1 (Criteria 1.1 and 1.3), a site must map its operational boundaries, owned or managed piping networks, direct water sources, water service providers and their ultimate hydrological sources, discharge points, wastewater service providers and ultimate receiving water bodies, and must quantify its site water balance including inflows, losses, storage and outflows alongside annual and seasonal variances. [S0302]

Empirical factory balances from textile wet processing show why separating intake sources and internal transformation steps is essential. In the 2023 PLOS study of 18 Bangladeshi textile wet-processing factories, total groundwater extraction averaged 164 litres per kilogram of fabric, whereas softened water delivered to the dyehouse averaged 136 litres per kilogram (representing between 68 and 100 percent of extracted groundwater across the sampled mills), and generated wastewater averaged 119 litres per kilogram. [S04] If a factory meters only its dyehouse header (136 litres per kilogram), it misses 28 litres per kilogram of upstream raw-water losses, ion-exchange softener regeneration backwash, boiler feedwater, cooling make-up and domestic sanitation consumption. [S04] Conversely, if it meters only the borehole pump (164 litres per kilogram) without submetering the dyehouse and the

effluent outfall (119 litres per kilogram), it cannot distinguish process bath inefficiency from underground pipe leakage, evaporative drying losses or unrecorded bypasses. [S04] [S05]

The water-governance mapping of Ethiopia's textile industry published by the Stockholm International Water Institute (SIWI) and the Sweden Textile Water Initiative provides a crucial African industrial benchmark for how source dependence and effluent governance interact. [S14] In that report, industrial water withdrawal in Ethiopia accounted for only 0.4 percent of total national water withdrawal according to the cited baseline profile, yet virtually all textile and garment factories relied on self-supplied borehole groundwater (with only a small minority tapping surface water or municipal networks). [S14] Crucially, the SIWI authors identified two structural governance failures that turned a modest national withdrawal share into a major local operational risk:

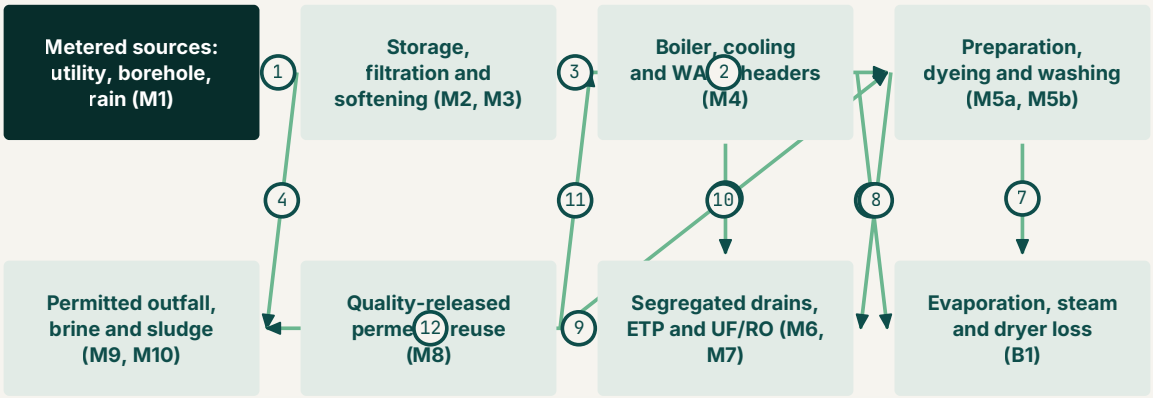
1. **Unmonitored groundwater extraction after licensing:** Once public authorities approved an industrial groundwater extraction licence and the number of boreholes an investor could drill, there was no systematic follow-up mapping the actual volume or frequency of pumping, leaving the country without a reliable inventory of industrial aquifer drawdown. [S14]
2. **Pollution risk exceeding quantity risk:** Many standalone textile and garment plants lacked functional effluent treatment plants and discharged liquid waste directly into nearby river bodies without adequate treatment or regulatory enforcement, leading the report to conclude that the sector faced higher water pollution risks than water quantity risks. [S14]

Global spatial risk frameworks corroborate the primacy of water quality and governance risks in textile manufacturing. In the World Resources Institute (WRI) Aqueduct 4.0 framework published on 16 August 2023, 13 global indicators are grouped into Physical Risk Quantity (eight indicators including baseline water stress, baseline water depletion, interannual variability, seasonal variability, groundwater table decline, riverine flood risk, coastal flood risk and drought risk), Physical Risk Quality (untreated connected wastewater and coastal eutrophication potential) and Regulatory and Reputational Risk (unimproved or no drinking water, unimproved or no sanitation, and the Peak RepRisk country ESG risk index). [S0301] In Aqueduct 4.0's industry weighting matrix (Table 3 of the technical note), the textile sector is assigned the maximum relevance weight of 4 on two specific indicators: untreated connected wastewater (Physical Risk Quality) and the Peak RepRisk country ESG risk index (Regulatory and Reputational Risk), while baseline water stress, baseline water depletion, interannual variability, coastal flood risk, unimproved drinking water and unimproved sanitation each receive a weight of 2, and seasonal variability receives 0.5. [S0301] At the same time, the WRI authors explicitly state in their limitations section that not every aspect of water risk has usable global datasets, noting that local water management, governance and local social dimensions are partially absent from global models. [S0301]

For a Cameroonian textile or garment facility, GFT synthesises the mass-balance architecture of the Bangladesh mill studies, the groundwater and effluent governance lessons of the Ethiopian mapping, and the site-scope requirements of the AWS Standard into the reconciled metering topology shown in **Exhibit 12**, p. 52. [S04] [S05] [S14] [S0302]

EXHIBIT 12 /

A reconciled site balance follows every intake to every discharge



1. Raw intake
2. Softened water
3. Filtered water
4. Backwash brine
5. Steam/cooling
6. Blowdown/WASH
7. Dryer carry-out
8. Spent baths
9. RO permeate
10. Matched rinse
11. Utility make-up
12. Effluent/sludge

DERIVED [S04] [S05] [S14] [S0302] Site water-balance and metering topology derived from the 18-factory and 15-mill wet-processing balances in Bangladesh (S04, S05), the groundwater and effluent governance findings in Ethiopia (S14) and Criterion 1.3 of the AWS International Water Stewardship Standard 2.0 (S0302). Each node represents a metered control boundary; no volumes are prefilled prior to site measurement.

In **Exhibit 12**, p. 52, ten physical meter boundaries (M1 through M10) and one calculated evaporative balance node (B1) prevent any single flow from disappearing into an unallocated residual. [S04] [S0302] Specifically:

- **Source separation (M1a, M1b, M1c):** Municipal mains, on-site boreholes, and surface or rainwater harvesting each carry their own flowmeter, totaliser and water-quality log. If municipal supply drops during a Douala or Garoua dry-season outage and the plant switches to buffered tank storage or borehole pumping, the shift log records the exact source substitution rather than masking it inside one aggregate intake figure. [S15] [S0302]
- **Pretreatment loss accounting (M2 to M3 and M4):** Raw water often requires sand filtration, iron removal or ion-exchange softening before it can enter reactive dyeing without causing shade unlevelness or boiler scaling. [S02] [S04] By metering raw intake (M2) against softened process output (M3) and utility output (M4), the

ledger isolates filter backwash and resin-regeneration brine (M2 to M10), which the 18-factory Bangladesh study showed can account for up to 32 percent of extracted groundwater in the most loss-prone mills (where dyehouse water was 68 percent of groundwater intake). [S04]

- **Process and utility separation (M5a, M5b vs M4):** Preparation and dyeing (M5a) are tracked separately from rinsing and garment washing (M5b), while boiler feed, cooling-tower make-up and worker water, sanitation and hygiene (WASH) flows (M4) remain on their own header. This satisfies both Higg FEM 4.0's requirement to separate unlike facility operations and the AWS Standard's requirement to verify on-site WASH access alongside industrial balances. [S24] [S0302]
- **Closed outfall reconciliation (M6, M7, M8, M9, M10):** Segregated drain collection (M6) feeds the effluent treatment plant (ETP) and any membrane polishing stage (M7), whose outputs must sum across recycled permeate (M8), final permitted discharge (M9) and removed concentrate or sludge (M10). [S06] [S14] What **Exhibit 12**, p. 52 cannot establish on its own is the acceptable chemical concentration at each node; for that, volumetric metering must be paired with an analytical effluent ledger. [S33]

3.5

Effluent quality needs its own account

A cubic metre of discharged textile wastewater is not equivalent to a cubic metre of withdrawn river water, even when the volume returned to the catchment equals 80 or 90 percent of the volume abstracted. Wet processing introduces salts, alkalis, organic sizing agents, surfactants, unfixed dyestuffs, optical brighteners and finishing resins that alter the temperature, pH, dissolved oxygen demand, salinity and toxicity of the receiving water body. [S01] [S02] [S31] Treating wastewater merely as a negative deduction from intake to compute "net consumption" hides the primary environmental pathway through which textile mills damage local catchments. [S14] [S0301]

International monitoring data demonstrate that industrial wastewater cannot be governed by relying on national or global statistical averages. In the 2024 mid-term progress report on SDG Indicator 6.3.1 (*Proportion of domestic and industrial wastewater flows safely treated*), UN-Habitat and the World Health Organization state for UN-Water that they remain unable to produce a global estimate of total and industrial wastewater flows because of pervasive national under-reporting. [S13] A detailed inspection of Table 1 and Section 3 of that 2024 UN-Water report exposes the scale of the industrial data void, as compiled in **Exhibit 13**, p. 54:

- While household wastewater generation is estimated across 193 UN Member States (covering more than 99 percent of the global population at 268 billion cubic metres per year) and safe household treatment is tracked across 129 Member States (covering 89 percent of the global population, with 58 percent safely treated), industrial wastewater reporting covers only a small fraction of countries. [S13]
- Across all UN Member States in the 2024 report, only 49 countries (representing 16 percent of the global population) reported the volume of industrial wastewater generated (totalling 36 billion cubic metres across those reporting states). [S13]

- Only 27 countries (10 percent of the global population) reported the volume of industrial wastewater treated (8 billion cubic metres), and only 22 countries (representing 8 percent of the global population) reported both generation and treatment variables needed to calculate the proportion of industrial wastewater receiving any treatment (38 percent for those 22 countries). [S13]
- Most strikingly, only 16 Member States (representing just 4 percent of the global population) reported data allowing UN-Water to calculate the proportion of industrial wastewater safely treated (defined as receiving at least secondary or equivalent treatment), yielding a subset statistic of 27 percent (3 billion cubic metres safely treated out of 3 billion cubic metres generated in the overlapping reporting subset, with 17 countries reporting safely treated volume covering 5 percent of global population). [S13]

EXHIBIT 13 / UN MEMBER STATES, % POPULATION, BILLION M3

Global industrial wastewater statistics suffer from severe national under-reporting

SDG 6.3.1 monitoring variable	Countries (2021)	Countries (2024)	Pop. share (2024)	Reported statistic (2024)
Household wastewater generated volume	193	193	>99%	268 bn m3
Household wastewater safely treated share	116	129	89%	58%
Total wastewater generated volume	56	85	46%	187 bn m3
Total wastewater safely treated share	15	42	12%	60%
Industrial wastewater generated volume	32	49	16%	36 bn m3
Industrial wastewater treated volume	15	27	10%	8 bn m3
Industrial wastewater treated share (any)	14	22	8%	38%
Industrial wastewater safely treated volume	3	17	5%	3 bn m3
Industrial wastewater safely treated share	3	16	4%	27%

SOURCED [S13] Transcribed from Table 1 (page xii) and Section 3 (page 38) of the 2024 UN-Habitat and WHO report for UN-Water on SDG Indicator 6.3.1 (S13). Because industrial reporting covers only 4 to 16 percent of the global population, UN-Water states that no valid global industrial wastewater estimate can be made.

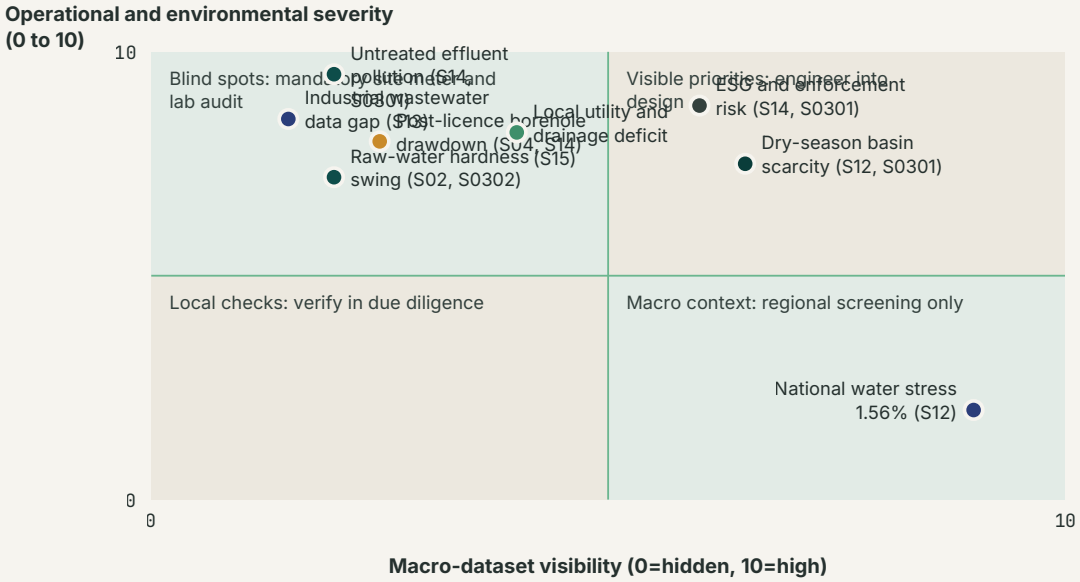
The numbers in **Exhibit 13**, p. 54 carry an immediate operational consequence for industrial benchmarking: when a country or region lacks comprehensive industrial wastewater statistics, an absence of published pollution figures reflects a monitoring gap rather than clean rivers. [S13] Even where targeted national surveys are conducted, coverage remains partial. In Box 7 of the same 2024 UN-Water report, an industrial and urban wastewater pilot conducted by the Environmental Protection Agency (EPA) of Ghana in collaboration with UN-Habitat for 2021/2022 received data from 150 facilities (143 industrial and 7 urban), representing 38 percent of the 400 facilities targeted. [S13] Those 150 reporting facilities consumed an estimated 29 million cubic metres of water per year and generated 11 million cubic metres of wastewater per year (85 percent from industries), carrying a combined annual pollutant load of 10,343 tonnes of nitrate, phosphorus, COD and BOD_5; notably, the 60 industrial facilities that operated wastewater treatment generated 63 percent of the total wastewater volume, while 83 industrial facilities had no wastewater treatment at all (accounting for 12 percent of total volume, with the urban facilities accounting for the remainder). [S13]

Because macro-level wastewater inventories cannot verify site compliance, a textile factory must maintain its own chemical-input and effluent-quality ledger. The ZDHC Wastewater Guidelines Version 2.2 (published in 2024 by the ZDHC Foundation) establish a unified industry expectation for testing industrial wastewater and sludge across conventional parameters, anions, heavy metals and Manufacturing Restricted Substances List (MRSL) chemicals. [S33] Crucially, ZDHC states that the purpose of testing ZDHC MRSL parameters in wastewater is to check for the intentional use of restricted substances or high levels of contamination in the chemical inputs entering the factory. [S33] Effluent quality is therefore not merely an end-of-pipe civil-engineering problem; it is an audit mirror of chemical purchasing, Safety Data Sheet (SDS) verification, recipe dosing and dye fixation. [S31] [S32] [S33]

Combining the hydrological, infrastructural, governance and reporting evidence across these international and national studies, **Exhibit 14**, p. 56 positions the eight primary water-risk dimensions that a Cameroonian textile project must evaluate across two operational axes: the degree to which external public datasets can detect the risk prior to site testing (horizontal axis, from 0 to 10) and the severity of the operational or regulatory disruption if the risk is left unmanaged at the factory gate (vertical axis, from 0 to 10). [S12] [S13] [S14] [S15] [S0301] [S0302]

EXHIBIT 14 / STRUCTURED RISK-SCREENING SCORE (0 TO 10 SCALE)

Water risk joins quantity, quality, governance and data coverage



SOURCED [S12] [S13] [S14] [S15] [S0301] [S0302] Structured screening placement derived from S12 (national vs basin stress), S13 (industrial wastewater under-reporting), S14 (Ethiopian textile groundwater dependence and pollution risk exceeding quantity risk), S15 (Douala potable-water and drainage deficits), S0301 (WRI Aqueduct 4.0 textile weights) and S0302 (AWS Standard 2.0 site-catchment scope). Site-specific measurements must replace screening scores before investment.

As **Exhibit 14**, p. 56 makes clear, the indicator with the highest visibility in international statistical tables, namely Cameroon's 1.56 percent national annual water-stress figure in the lower-right quadrant, carries the lowest direct diagnostic power for a specific factory plot. [S12] Conversely, the four hazards clustered in the upper-left quadrant ("Blind spots: mandatory site meter and lab audit") combine high operational severity with low visibility in macro-databases: untreated industrial effluent pollution, the global and national industrial wastewater reporting gap, unmonitored post-licence borehole drawdown, and seasonal raw-water hardness or salinity swings. [S02] [S04] [S13] [S14] [S0301] [S0302] While **Exhibit 14**, p. 56 organises the screening priorities for GFT's site-selection tool, the coordinates are illustrative structured rankings derived from those cited risk frameworks rather than physical measurements of a specific Cameroonian parcel; each blind spot must be converted into a physical meter and sampling point during site due diligence. [S0301] [S0302]

3.6

Reuse changes the balance rather than erasing impact

When faced with local intake constraints or strict outfall limits, project sponsors frequently propose wastewater recycling or "zero liquid discharge" (ZLD) as a universal technical fix. Chapter 10 of this paper examines treatment trains and fit-for-purpose water quality in full engineering detail, but the foundational accounting rule belongs here in Part I: water reuse changes the internal circulation and phase distribution of water, salts and energy inside the factory boundary; it does not make environmental impacts disappear. [S06] [S10]

A documented industrial case study of a textile dyeing and finishing plant in Foshan, China, published in MDPI Processes on 11 January 2019, illustrates both the technical potential and the physical trade-offs of advanced water reuse. [S06] The Foshan facility treated textile wastewater using a combined train of two-stage ozonation, ultrafiltration (UF) and reverse osmosis (RO), achieving a whole-system recycled water reuse rate of 86.8 percent (which exceeded a comparative forward-osmosis and reverse-osmosis reference system by 31.8 percentage points). [S06] That 86.8 percent recovery rate is an empirical result achieved on that specific system and effluent profile; it must not be imported into a Cameroonian feasibility model as a guaranteed recovery factor. [S06]

More importantly, the Foshan study demonstrates that high-recovery membrane recycling creates three linked physical and economic obligations that must remain visible on the factory resource ledger:

1. **Non-zero reject concentrate and sludge streams:** An 86.8 percent recovery rate across the reuse system means that 13.2 percent of the volume (along with the vast majority of the rejected dissolved inorganic salts and residual recalcitrant organics separated by the reverse-osmosis membranes) exits as concentrated brine or sludge requiring lawful secondary treatment, evaporation or disposal. [S06] [S33] Reducing liquid volume without eliminating dissolved mass increases the concentration of total dissolved solids in the residual stream.
2. **Substantial treatment electricity demand:** In the Foshan operating-cost analysis, electricity consumed by the ozone generators, high-pressure reverse-osmosis feed pumps and ultrafiltration units constituted a primary share of total treatment operating cost. [S06] Where a factory relies on carbon-intensive grid power or expensive diesel backup generation during grid interruptions, every cubic metre of RO permeate carries a measurable kilowatt-hour and Scope 1 or Scope 2 emissions burden. [S06] [S19] [S25]
3. **Strict quality-release gates for the next process duty:** Recycled water can re-enter preparation, dyeing, rinsing or boiler make-up only if its residual colour, conductivity, hardness, alkalinity and organic load meet the tolerance of that specific operation. [S01] [S02] [S06] If poorly polished recycled water is fed into a sensitive reactive dye bath and causes shade unlevelness or poor wash fastness, the resulting stripping and re-dyeing cycle consumes far more water, steam and chemistry than the reuse loop saved. [S37]

WORKED EXAMPLE

Illustrative mass, salt and energy ledger for once-through versus partial-reuse wet processing

To demonstrate how GFT's accounting equations prevent a reuse claim from hiding concentrate or energy burdens, consider an **illustrative** engineering calculation for a hypothetical batch dyehouse processing $Q_{\text{gross}} = 1,050\text{ kg}$ of cotton knit fabric, of which $Q_{\text{acc}} = 1,000\text{ kg}$ passes first-time quality release and 50 kg requires reprocessing (an illustrative 4.76 percent reject/rework share). All numbers in this box are **illustrative** model inputs chosen solely to demonstrate the accounting method; they are not observations from a GFT facility or forecasts for a Cameroonian site. [S04] [S06]

- **Case A (Illustrative once-through baseline):**
- Assume total metered freshwater intake across preparation, reactive dyeing, rinsing, softening backwash and utilities for the batch cycle (including the reprocessed 50 kg) is an illustrative $W_{\text{in,A}} = 140\text{ m}^3$ ($140,000\text{ litres}$), within the empirical range observed in the Bangladesh mill studies. [S04] [S05]
- Against gross production ($1,050\text{ kg}$), apparent illustrative intensity would be $140,000 / 1,050 = 133.3\text{ L/kg}$, whereas against accepted output ($Q_{\text{acc}} = 1,000\text{ kg}$), the illustrative operational freshwater intensity is $I_{\text{fw,A}} = 140,000\text{ L} / 1,000\text{ kg accepted} = 140.0\text{ L/kg accepted}$.
- Assume an illustrative $W_{\text{cons,A}} = 20\text{ m}^3$ ($20.0\text{ L/kg accepted}$) is evaporated in stenters, dryers and steam losses, leaving an illustrative $W_{\text{out,eff,A}} = 120\text{ m}^3$ ($120.0\text{ L/kg accepted}$) discharged to the effluent treatment plant.
- If the batch uses an illustrative 500 kg of inorganic electrolyte (salt) and alkali in reactive dyeing plus 100 kg of softener regeneration salt (600 kg total dissolved inorganic solids), the average total dissolved solids (TDS) concentration in the 120 m^3 effluent stream (above raw-water background) is an illustrative $\Delta C_{\text{TDS,A}} = 600,000\text{ g} / 120\text{ m}^3 = 5,000\text{ mg/L}$ (5.0 g/L).

- **Case B (Illustrative segregated rinse recovery via UF + RO polishing):**
- Suppose the mill segregates an illustrative 75 m^3 of lower-salinity rinse and washing effluent (containing an illustrative 150 kg of the dissolved salt load, or $2,000\text{ mg/L}$) and sends it to an ultrafiltration and reverse-osmosis train operating at an illustrative 80.0 percent volumetric recovery (below the 86.8 percent reported in the Foshan case), while the remaining 45 m^3 of high-strength spent dye bath and backwash (containing 450 kg of salt, or $10,000\text{ mg/L}$) goes through conventional biological and chemical ETP treatment for discharge. [S06]
- The RO unit produces an illustrative $W_{\text{rec,B}} = 0.80 \times 75\text{ m}^3 = 60\text{ m}^3$ of low-conductivity permeate, which replaces 60 m^3 of incoming freshwater in rinsing and washing, and generates an illustrative $W_{\text{out,conc,B}} = 0.20 \times 75\text{ m}^3 = 15\text{ m}^3$ of membrane reject concentrate.
- Because illustrative process demand (140 m^3 total water to machines and utilities) and evaporative consumption ($W_{\text{cons,B}} = 20\text{ m}^3$) remain unchanged, external freshwater intake drops to an illustrative

$W_{\text{in,B}} = 140\text{ m}^3 - 60\text{ m}^3 = 80\text{ m}^3$, giving $I_{\text{fw,B}} = 80,000\text{ L} / 1,000\text{ kg accepted} = 80.0\text{ L/kg accepted}$.

- However, the illustrative ledger must simultaneously record the three companion accounts:
- **Total process liquor intensity** remains an illustrative $140.0\text{ L/kg accepted}$ (80.0 L/kg fresh plus 60.0 L/kg recycled permeate).
- **Liquid outflow and salt concentration:** Total liquid leaving the site drops from 120 m^3 to an illustrative $45\text{ m}^3 + 15\text{ m}^3 = 60\text{ m}^3$ ($60.0\text{ L/kg accepted}$). Because membranes reject rather than destroy inorganic salt, nearly all 600 kg of salt remains in that 60 m^3 combined outflow (roughly 147 kg in the 15 m^3 RO concentrate at $\approx 9,800\text{ mg/L}$ assuming an illustrative 98 percent salt rejection, plus 450 kg in the 45 m^3 high-strength stream), raising the blended outfall TDS addition from $5,000\text{ mg/L}$ in Case A to an illustrative $\approx 9,950\text{ mg/L}$ in Case B unless a dedicated salt-recovery or brine-management step is added.
- **Auxiliary treatment energy:** At an illustrative specific electricity demand of 3.5 kWh/m^3 of feed treated across pretreatment, UF and high-pressure RO pumping, processing 75 m^3 adds an illustrative $75 \times 3.5 = 262.5\text{ kWh}$ ($0.263\text{ kWh/kg accepted}$) to the facility's electrical ledger. [S06]

By reporting the illustrative values $I_{\text{fw,B}} = 80.0\text{ L/kg}$, $I_{\text{rec,B}} = 60.0\text{ L/kg}$, $I_{\text{out,B}} = 60.0\text{ L/kg}$, $\Delta C_{\text{TDS,B}} \approx 9,950\text{ mg/L}$ and $E_{\text{reuse,B}} = 0.263\text{ kWh/kg}$ on the same row, the engineer sees the exact trade-off between freshwater conservation, brine management and electrical load. [S06]

GFT NOTE

Practical recommendation for the Cameroon textile programme

In GFT's Cameroon textile programme, the base operating model centres on cut-make-trim garment manufacturing and finishing, linked to partnered or staged upstream spinning, weaving and wet processing. [R06] [S24] To ensure that water decisions are engineered into site selection and supplier contracting from the first shift, GFT recommends a four-part protocol connecting this paper to `wp05` (provenance and traceability), `wp16` (life-cycle and carbon accounting) and `wp17` (chemical and environmental compliance), as well as the interactive `footprint` and `site-selection` tools:

1. **Separate owned garment-plant meters from partner wet-process ledgers:** In accordance with Higg FEM 4.0, GFT's owned garment lines must meter municipal and borehole intake, steam-boiler feed, evaporative cooling, garment washing and sanitation per accepted piece, while requiring any contracted domestic or regional dyehouse to report batch-level freshwater intake, recycled water, effluent volume and ZDHC-aligned wastewater test results per accepted kilogram of fabric. [S24] [S33]
2. **Require catchment-specific hydro-environmental baselines before site commitment:** Whether evaluating a coastal plot near Douala or Dibamba or a northern plot near Garoua, project sponsors must never rely on Cameroon's 1.56 percent national water-stress indicator. [S12] Site due diligence must include dry-season borehole or utility yield verification, raw-water seasonal chemistry, drainage and flood-elevation mapping, and receiving-water low-flow assimilation capacity. [S15] [S0302]
3. **Design segregated drains into the civil slab before pouring concrete:** Retrofitting pipe segregation after a dyehouse or laundry floor is built is costly and disruptive. Civil layouts should separate cooling and condensate returns, low-salt countercurrent rinse streams, high-salt reactive dye baths and domestic sewage from the outset so that future reuse trains treat only the streams that match their membrane or biological duty. [S01] [S02] [S06]
4. **Enforce chemical input control as the primary effluent defence:** Following the Ethiopian governance lesson that pollution risk can exceed quantity risk and the ZDHC rule that wastewater testing audits chemical inputs, no dyestuff, auxiliary or finishing agent should enter a GFT-owned or partnered wash recipe without a verified Safety Data Sheet and MRSL conformance record. [S14] [S32] [S33]

A flowmeter records how many litres crossed the pipe; only the catchment, the season and the outfall reveal what those litres cost.

CHAPTER SOURCE NOTES

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S14 Sweden Textile Water Initiative, Stockholm International Water Institute. 2017.

S06 MDPI, Processes. 2019-01-11.

S10 Earthscan, for Water Footprint Network. 2011.

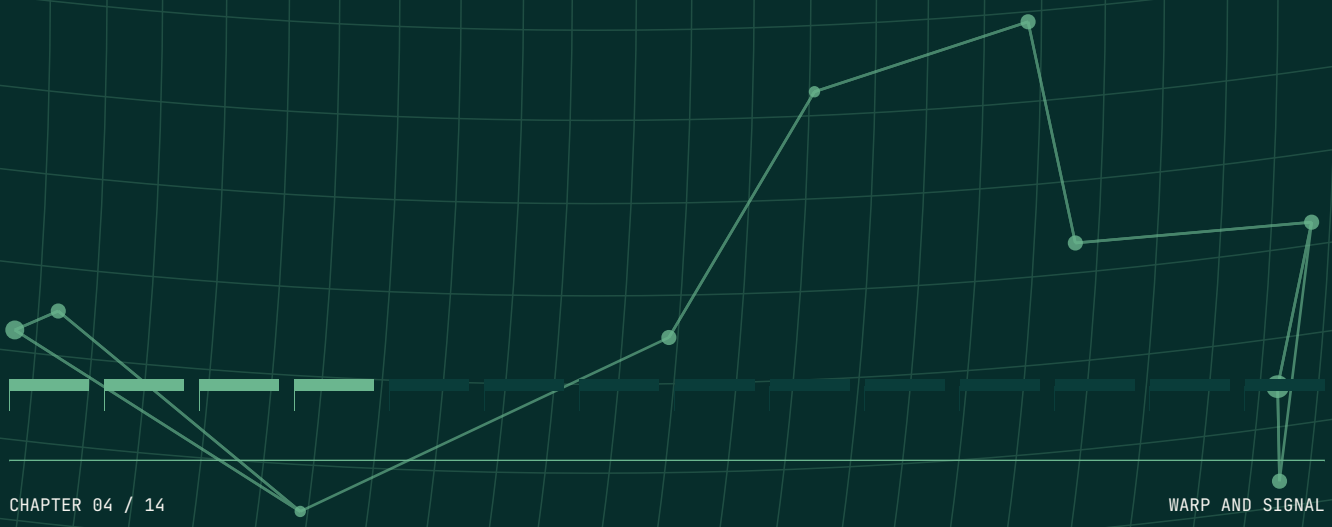
S11 International Organization for Standardization. 2014-07-24.
R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.
R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.
S09 Elsevier, Ecological Economics. 2006.
R03 SODECOTON. Publication date unrecorded; inherited source-text check.
S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.
S04 PLOS Sustainability and Transformation. 2023-07-31.
S0302 Alliance for Water Stewardship. 2019-03-22.
S13 UN-Habitat and World Health Organization, for UN-Water. 2024.
S33 ZDHC Foundation. 2024.
S24 Sustainable Apparel Coalition. 2022.
S05 MDPI, Textiles. 2022-09-28.
S18 International Organization for Standardization. 2018.
S23 Textile Exchange. 2025-08-07.
S02 European Commission Joint Research Centre. 2023.
S12 Food and Agriculture Organization of the United Nations and UN-Water. 2024.
S15 World Health Organization. 2025-09-26.
R09 Ecofin Agency. Publication date unrecorded; inherited source-text check.
R10 Ecofin Agency. Publication date unrecorded; inherited source-text check.
R12 Business in Cameroon. Publication date unrecorded; inherited source-text check.
S0301 World Resources Institute. 2023-08-16.
S25 World Bank. 2025-06-25.
S31 Springer Nature, Scientific Reports. 2022-12-26.
S32 ZDHC Foundation. 2023.
S19 GHG Protocol. 2015.
S37 Emerald Publishing Limited. 2019.

04

PART I: DEFINE THE UNIT BEFORE REDUCING IT / DYE AND CHEMISTRY

Colour control is a resource-control system

A shade is resource-efficient only when its accepted result includes the chemistry, washing, corrections and discharge needed to produce it.



CHAPTER 04
DECISION TEST

A shade is resource-efficient only when its accepted result includes the chemistry, washing, corrections and discharge needed to produce it.

Colour control should govern a complete resource account, from chemical receipt to the release of dyed fabric. GFT recommends linking the approved recipe, measured dye uptake, durable fixation, shade decision and every corrective operation under a common batch identity. The decision is whether a route repeatedly makes acceptable cloth with lower whole-cycle demand, while meeting chemical and discharge requirements. A pale residual bath, a close colour match or a lower chemical invoice alone cannot establish that result. This chapter specifies an operating method, rather than reporting an achieved GFT factory saving.

4.1

Fibre and dye route determine the resource problem

The starting mechanism is specific to the substrate and colour chemistry. In reactive cotton dyeing, salt promotes exhaustion and alkali supports fixation; the reviewed experimental literature distinguishes these functions. IFC's textile guidance connects water use with wastewater, sludge and heating demand. These relationships justify investigating colour as a coupled production and resource decision, rather than a stand-alone dye-purchasing decision. [S31] [S01]

GFT proposes that a route record begin with fibre composition, fabric construction, preparation-lot identity, customer shade reference and required end use. Treat these as conditions of recipe approval. The record should then name the machine, loading envelope, water source, chemical formulations and authorised process sequence. This is a proposed control structure. It does not imply that a recipe validated on a pure cotton substrate is approved for a blend, or that a similar commercial colour name establishes comparable behaviour.

The useful comparison is between routes that deliver the same required product. Before a trial, the process engineer should write down which conditions will be held constant and which are being changed deliberately. A lower dye charge is only a candidate improvement until the resulting shade, fastness and accepted output are checked. Similarly, the purchasing team should retain delivered formulation concentration and dilution instructions, so an apparently cheaper kilogram does not conceal a change in the active material supplied.

Make the water used to prepare the recipe part of that record. The hard-water study found that hardness and dye concentration influenced its right-first-time result. GFT therefore proposes recording water-quality checks beside dosing and temperature histories, rather than interpreting a shade deviation through dye quantity alone. The study's operating conditions remain study-specific; they are not setpoints for a proposed Cameroon production line. [S37]

A recipe should have distinct target, permitted range and stop conditions. The target describes the intended process. The permitted range is supported by product trials. The stop condition identifies a departure requiring authorisation, such as unavailable source-water information or an unapproved formulation substitution. Leave those ranges unset until validation exists. Filling an empty engineering field with a generic industry value would create an instruction without evidence.

The shift operator needs a compact instruction derived from the approved master recipe. The laboratory needs the full analytical history. Purchasing needs an approved-product reference. Management needs the resource consequence of deviations. GFT recommends connecting these views to the same recipe version, while preserving their different purposes. A revised dosing sequence should not silently inherit approval from the previous sequence merely because the product code remains unchanged.

Use an exception record for any substitution made under supply pressure. State what changed, which batches received it, who approved the trial and which release evidence is required. Keep unaffected batches separately identifiable. If the substitution fails, the record should support containment without treating all production in the reporting period as chemically equivalent. The resource account can then distinguish the cost of a tested improvement from the cost of an uncontrolled change.

This chapter stops at the interface with substrate preparation and machine selection. It requires their lot and route identities because colour interpretation depends on them. Detailed preparation design and low-liquor equipment comparison belong in the following chapters. Here, the practical question is whether the colour decision retains enough information to identify what was consumed, what was accepted and what must be investigated when those outcomes diverge.

Before running a new colour family, GFT recommends a short readiness review involving production, quality, utilities and chemical management. Confirm that the route instruction matches the laboratory approval, required input checks are available and the metering boundary can capture any correction. If a required measurement cannot be taken, record the resulting limitation before the trial starts. That prevents the team from discovering after production that its most important comparison depends on an unrecorded assumption. Keep the review proportional to the change, but make its decision recoverable from the batch record.

4.2

Exhaustion and fixation belong on the batch record

Exhaustion describes transfer out of the bath; fixation concerns the dye retained after unfixed material is removed under the analytical method. The reactive-dye study measures both, using bath analysis and a subsequent extraction procedure. GFT recommends preserving the measurement basis with each result. In particular, a fixation percentage expressed relative to exhausted dye must not be presented as the same percentage of dye originally charged. [S31]

For the proposed ledger, define charged dye mass as D, dye exhausted onto fabric as U and analytically retained dye as F. Record exhaustion as U divided by D, fixation relative to uptake as F divided by U, and retained share of charge as F divided by D. Express each as a percentage only after naming its denominator. These are GFT accounting definitions for a trial protocol; the laboratory must reconcile them to its validated analytical method before reporting production results.

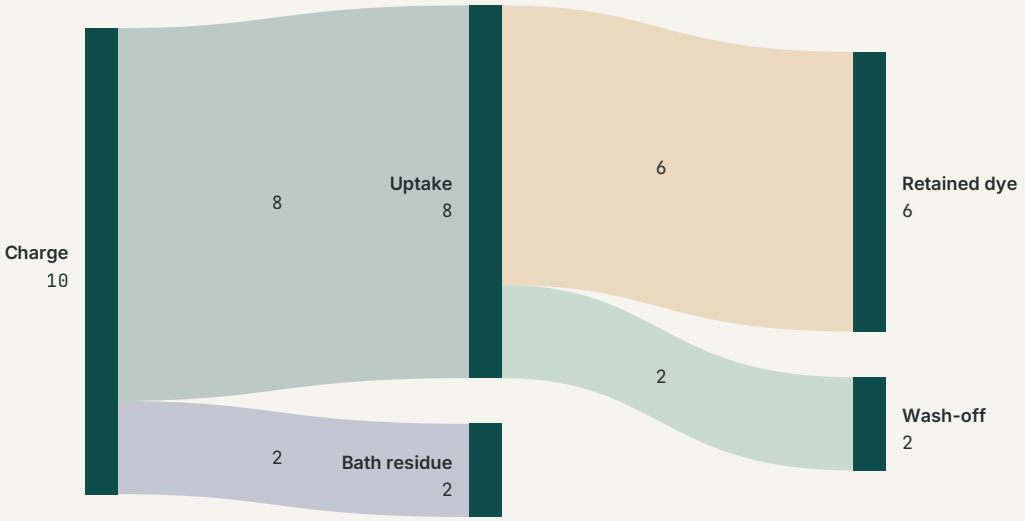
WORKED EXAMPLE: UPTAKE DOES NOT EQUAL RETAINED DYE

An illustrative closed balance assumes 10 kg of active dye charged, 8 kg transferred onto the fabric and 6 kg retained after the specified wash-off analysis. Exhaustion is 8 / 10 = 80 percent. Fixation relative to uptake is 6 / 8 = 75 percent. Retained dye relative to charge is 6 / 10 = 60 percent. The remaining 4 kg comprises 2 kg in the residual bath and 2 kg removed from the fabric during washing. These assumed masses explain denominators; they are not observed GFT results or a recommended recipe.

The illustrative flow in **Exhibit 15**, p. 65 preserves those mass boundaries. Its fabric branch represents retained dye, not a disposal credit. Its liquid branches are streams requiring measurement and management, not proof that treatment removes the dye or renders the discharge acceptable. A real investigation would also need retained liquor, sampling losses and any other material paths before calling the balance closed.

EXHIBIT 15 / KG ACTIVE DYE, ILLUSTRATIVE

Uptake and retained dye have different denominators



ILLUSTRATIVE Assumed closed balance: 10 kg charged = 8 kg uptake + 2 kg residual bath; 8 kg uptake = 6 kg retained + 2 kg wash-off. Exhaustion 80%; fixation of uptake 75%; retained share of charge 60%. No GFT measurement or treatment-removal claim.

For a production trial, GFT proposes sampling the charge, residual bath and wash streams through a laboratory-approved protocol. Record sample time, dilution, bath volume, instrument calibration and analytical uncertainty. Concentration alone cannot close a mass account if volume changes during dosing, drainage or replenishment. Preserve the measurements needed to calculate concentration multiplied by volume at the relevant boundary, together with the uncertainty introduced by unmeasured carryover.

Mixtures need particular care in the proposed protocol. Ask the laboratory whether its method distinguishes the components sufficiently for the decision being made. If it cannot, report the aggregate result with that limitation. Do not allocate a blended residual among individual dyes by guesswork. A spectral signal should not be relabelled as active dye mass unless the calibration and matrix support the conversion.

GFT also recommends recording results by dye identity and recipe, rather than assigning a universal fixation factor to the dyehouse. A comparison of alternative recipes should retain substrate, shade, water and analytical conditions. Where the evidence cannot separate recipe effects from measurement variation, the appropriate outcome is another controlled trial or an unresolved result. Publishing a precise-looking average would not resolve that uncertainty.

Finally, retain the balance residual as an explicit field. Ask whether it is consistent with stated measurement uncertainty before investigating its cause. A non-closing balance is a reason to inspect volumes, sample labels, dilution calculations and material paths. It is not permission to force the retained-dye estimate to the value required by the business case. This prevents an accounting adjustment from masquerading as chemical performance.

Analytical sampling should also have a disposition rule. GFT proposes labelling specimens with the parent lot and process stage, retaining the chain of custody and specifying how repeat analysis will be handled. If a specimen is contaminated or its identity becomes uncertain, replace it through the agreed sampling procedure and preserve the invalidated result with the reason. Do not average a disputed result into the accepted dataset. The same rule should apply to an inconvenient low result and an apparently favourable high result, so the measurement process does not depend on the desired conclusion.

4.3

Colour difference converts quality into a release rule

GFT proposes a shade-release record that states the reference, instrumental method, visual assessment conditions, tolerance, sampling positions and approving role. The record should show the measured result and the applicable criterion separately. An approval tick without the underlying result cannot reveal whether performance is drifting towards the edge of the agreed tolerance. Retain instrument identity and calibration status so later investigations can distinguish process variation from a change in measurement practice.

The hard-water study uses instrumental colour measurements, including colour strength and colour difference. GFT recommends treating these as complementary observations within an agreed release method. Shade agreement does not by itself demonstrate durable fixation or acceptable fastness. Conversely, satisfactory resource measurements cannot authorise fabric outside its product specification. The release system should retain independent quality and resource decisions. [S37]

Do not invent a universal colour-difference threshold for the chapter. The buyer's agreed method, product use and validated measurement procedure should determine the threshold used in an actual contract. Record the formula as well as the value, since an unqualified colour-difference label leaves the calculation ambiguous. Retain the selected illuminant, observer and specimen preparation as controlled method fields. Changes to those fields require an explicit comparability assessment.

For sampling, GFT recommends defining how the selected specimens represent the batch before measurement begins. Identify their positions in the roll or garment lot, how repeat readings are treated and what triggers additional examination. Report the spread where it matters to the decision. An average close to the target should not erase a local failure that would remain visible in the finished product. An operator should be able to identify the affected material from the release record.

The illustrative release table in **Exhibit 16**, p. 67 organises proposed evidence without assigning numerical thresholds. It uses a table because the requirements are distinct gates, not scores on an invented common scale. Its purpose is to make missing evidence visible. It cannot establish that a particular instrument, test method or customer requirement has been validated for the proposed site.

EXHIBIT 16 / PROPOSED RECORD FIELDS

Colour release needs independent evidence gates

Gate	Retain	Decision
Shade	Method and result	Match agreed target
Fastness	Test and specimen	Meet product requirement
Chemistry	Product and lot	Approve formulation
Resource	Whole-cycle ledger	Accept or investigate
Authority	Role and timestamp	Release or hold

ILLUSTRATIVE Illustrative GFT release structure. Thresholds, sampling plans and methods require product-specific agreement and validation. Rows are not certification criteria or evidence of a GFT operating result.

Use explicit held, released, corrected and rejected states in the proposed workflow. A held lot has not become accepted output simply because production has physically finished. A corrected lot may eventually be released, but its correction remains part of its history. Preserve both the initial result and the final result, rather than replacing the failed reading with the successful one. This supports honest resource accounting and useful diagnosis.

Where instrumental and visual assessments disagree, the responsible quality role should follow a pre-agreed escalation rule. Retain the disagreement and its resolution. Do not let the production dashboard average the observations into an apparently acceptable result. GFT recommends recording whether the issue concerns target agreement, within-batch variation, measurement uncertainty or an unresolved method discrepancy, since each calls for a different investigation.

Keep customer concessions visible as concessions. If a buyer accepts a deviation, preserve the original criterion, measured departure and authorised disposition. Do not rewrite the original release specification after the event to improve the apparent right-first-time result. A separately reported concession category lets management distinguish process capability from commercial judgement without questioning the legitimacy of an authorised sale.

For management review, connect each held or corrected lot to the process history available at the time of its first release decision. Ask what evidence would have prevented the failure and whether that evidence was available to the operator. This turns colour control into an engineering feedback loop. It also avoids blaming the laboratory for detecting a failure caused earlier in the route or by an inadequately specified input.

Retain a reference specimen under the agreed storage and handling procedure, and give it a controlled identity linked to the approved target. GFT proposes documenting any replacement of that reference and checking whether the replacement changes the interpretation of earlier results. When a customer revises a target, treat the revision as a new specification event rather than a process improvement. Otherwise a more permissive target could make the dashboard appear to improve even though the underlying fabric and resource demand remained unchanged. Management should be able to distinguish that event from a genuine improvement in process repeatability.

4.4

Right-first-time is a water and energy intervention

The right-first-time literature connects corrective dyeing with extra water, energy and effluent. It provides the mechanism for counting correction as a resource variance as well as a quality variance. It does not provide a transferable saving percentage for an unmeasured GFT operation. GFT recommends measuring each repeated operation and keeping it attached to the originating lot. [S37]

Define right-first-time before presenting the indicator. The proposed rule is acceptance at the first scheduled release decision, without an unplanned adjustment or corrective operation. The planned route must be agreed in advance; a standard wash-off stage is not automatically rework. Equally, an extra wash introduced after a failure must not be retrospectively described as planned processing. Store the reason and authorisation for every additional operation.

Use separate batch-count and mass-weighted indicators where batch sizes differ. The proposed batch-count indicator divides lots accepted first time by lots reaching their first release decision. The mass-weighted indicator uses their original processed masses at the same boundary. Neither should count a corrected lot as a fresh successful first attempt. Report final accepted mass separately so a useful quality measure does not become a disguised production denominator.

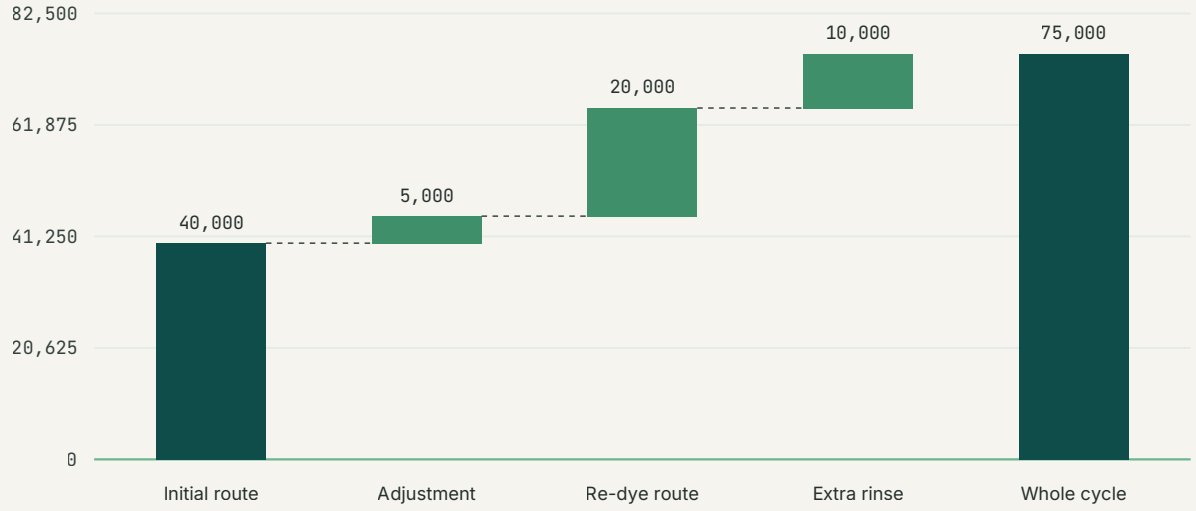
For resource accounting, maintain a parent batch identity and child operation records. Each correction should state its purpose, start and finish, water, chemicals, thermal energy, electricity and resulting disposition. Count the final released fabric once. The

procedure should also retain resources spent on lots eventually rejected. Otherwise the quality failures most relevant to management would disappear from the accepted-unit account precisely because they failed.

The illustrative water bridge in **Exhibit 17**, p. 69 shows how a limited first-pass view understates the total. Water is the only physical unit in this exhibit. Heating, pumping electricity, chemicals and occupied machine time belong in separate ledgers. Those quantities can later be valued through explicit prices, but they should never be added directly to litres as though they were the same physical measure.

EXHIBIT 17 / LITRES, ILLUSTRATIVE BATCH

Correction water remains attached to the released lot



ILLUSTRATIVE Assumed 1,000 kg finally accepted: initial route 40,000 L; adjustment 5,000 L; re-dye route 20,000 L; extra rinse 10,000 L. Total 75,000 L; intensity 75 L/kg rather than first-pass 40 L/kg. Heat, chemicals and time are excluded from this water-only bridge.

WORKED EXAMPLE: ACCEPTED OUTPUT RETAINS THE CORRECTION BURDEN

In the illustrative water bridge, assume the same 1,000 kg lot is finally accepted after all operations. Its whole-cycle water intensity is (40,000 + 5,000 + 20,000 + 10,000) / 1,000 = 75 litres per accepted kilogram. Reporting the initial route alone gives 40 litres per kilogram and omits 35,000 litres. That omitted quantity is 46.7 percent of total cycle water, rounded from 35,000 / 75,000. Preventing the entire correction sequence would reduce water by that amount under these assumptions only. No measured saving, energy saving or production forecast is implied.

When a correction handles only part of a lot, GFT recommends recording the physical split and linking both resulting quantities back to the parent. State whether meters measure the correction directly or whether an allocation is estimated. A shared wash carried out across lots needs an allocation rule approved before comparison. Keep the unallocated remainder visible rather than distributing it silently to whichever lot has the highest apparent margin.

A resource review should ask why correction occurred before selecting an improvement. Group the recorded causes by recipe, water condition, substrate, dosing, measurement and other documented factors. Preserve an unknown category when evidence is missing. Repeated association can justify a controlled investigation, but it does not prove causation. Use paired trials to test the proposed explanation before converting a corrective action into a permanent recipe change.

GFT recommends reviewing resource and quality exceptions together at an operating meeting. Select actions from the recorded causes, assign a responsible role and state the observation that would demonstrate improvement. Keep completion of an action separate from verification of its effect. An operator briefing may be completed while the next comparable batch remains untested. Closing the action only after the relevant outcome is observed prevents a dashboard of completed tasks from being mistaken for a dashboard of reduced resource demand. Where product mix changes, retain that qualification beside the comparison.

4.5

Chemical conformance starts at the input inventory

Input evidence, product requirements and discharge evidence need separate records. ZDHC's formulator guidance requires Safety Data Sheets for conformant products and describes review of product identity and formulation information. GFT recommends linking the approved commercial formulation to the supplier, received lot, current documentation and batches consuming it. A generic supplier folder is insufficient if the consumed product cannot be matched to its evidence. [S32]

For the proposed inventory, retain product name, formulation version, supplier, delivery reference, received quantity, container identity and storage location. Link the Safety Data Sheet and any conformance evidence as dated documents rather than unversioned web links. Record who checked their scope and what unresolved question remains. The inventory should support both a recipe authorisation decision and a search for batches affected by a later supplier notification.

Use a receipt hold when the delivered product identity does not match the approved record. The purchasing role can seek clarification; the chemical-management role can assess the evidence; the process role can decide whether validation is needed. GFT recommends documenting those responsibilities before an urgent delivery arrives. Do not allow a similar trade name to serve as proof of an unchanged formulation or an approval transferred from a different product.

The historical European measure introducing REACH Entry 72 illustrates a different boundary: specified substances in defined consumer clothing, textile and footwear articles, assessed through concentration in homogeneous material and subject to exclusions. This chapter uses the adopted text to explain that distinction, not to certify current legal compliance for a product or market. Current applicability requires a product-specific review of the governing rules. [S34]

OEKO-TEX's January 2025 announcement records a BPA limit change from 100 to 10 mg/kg within its revised standards. GFT uses this dated example to show why a requirements register needs version and effective-date fields. It is not presented as the complete requirement set in force at the edition date, a universal textile law, or a GFT certification. [S35]

The proposed requirements register should therefore identify the market, product category, buyer requirement, scheme where relevant, applicable version, effective date, sampling method, analytical method and approving role. Keep input-chemical conformance separate from finished-product test results. Neither record should automatically populate the other's approval field. The engineering question is what the document actually demonstrates about the material being released, not how many certificates have been collected.

> **GFT NOTE**
>
> Authorise the formulation, not merely the supplier. Before trial use, match the delivered product to its evidence, review handling requirements and define the product and effluent tests needed. Keep any unresolved identity, safety or applicability question as a hold. The approval should travel with the recipe version and received lot into the batch ledger.

For inventory reconciliation, compare opening stock plus receipts with recorded consumption, authorised returns, disposal and closing stock. Keep commercial formulation mass separate from active-dye mass used in an analytical balance. GFT recommends investigating unexplained differences through physical counts and transaction records. A stock discrepancy should not automatically be classified as process loss, since that would mix purchasing, storage and chemical-performance questions without evidence.

When a document expires or a requirement changes, assess affected stock, approved recipes and outstanding orders separately. Preserve the decision taken for each affected group. The response may involve seeking updated evidence, replacing a formulation, validating an alternative or holding material. This is an administrative control linked to production identity, not an assertion that any particular certificate status determines every legal or commercial outcome. The chapter is an engineering framework, not investment, legal or tax advice.

Access to the proposed chemical record should reflect operational responsibility. Operators need clear approved instructions and handling information; reviewers need the supporting documents; system administrators need a controlled way to manage access without changing technical approval. GFT recommends recording edits to product identity, recipe approval and inventory disposition, including the previous value and reason. A corrected clerical error should remain distinguishable from a changed formulation. This preserves a usable history without requiring the shift team to reconstruct decisions from an informal message thread during a production hold.

4.6

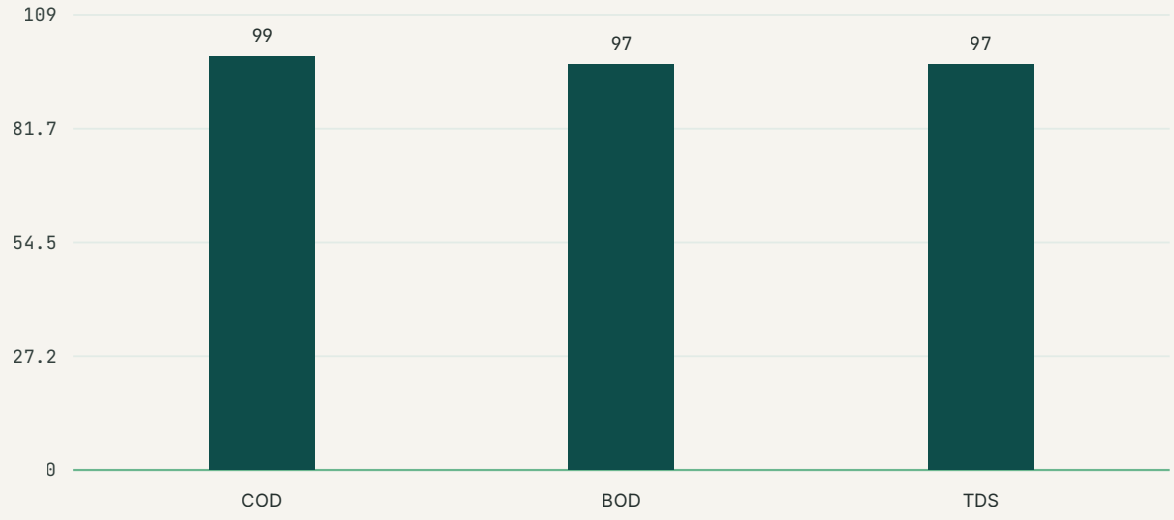
Recipe improvement requires whole-effluent verification

A laboratory TNA study reported residual-dyebath COD, BOD and TDS reductions of 99, 97 and 97 percent against its conventional comparison. Those are results for the tested chemistry and sampling boundary, not measured whole-factory load reductions. They warrant investigation, not automatic adoption. GFT would require independent chemical-safety review and representative trials before treating the route as a production option. [S31]

The study's findings in **Exhibit 18**, p. 72 are deliberately labelled as laboratory comparisons. The chart reports relative reductions for separate parameters. It does not sum them into a combined environmental score or imply the same remaining pollution mass for each. The proposed site decision must retain absolute concentrations, corresponding stream volumes, all wash streams and the treatment boundary before estimating any whole-cycle load change.

EXHIBIT 18 / PERCENT REDUCTION, TESTED RESIDUAL DYEBATH

Laboratory effluent reductions require a site-scale test



SOURCED [S31] Aysha et al. (2022), RY145 residual-dyebath comparison using TNA against conventional chemistry: COD 99%, BOD 97%, TDS 97%. Laboratory results, not GFT data, whole-factory loads, safety approval or guaranteed production savings.

GFT proposes a trial scorecard with independent acceptance conditions for colour, fastness, chemical evidence, worker handling, resource use, effluent and cost. Do not offset an unresolved safety question with a water benefit. Similarly, a lower salt charge should remain a recipe observation until the whole account establishes what changed elsewhere. The decision should record which conditions passed, failed or remain unresolved, and who owns the evidence needed to close each question.

ZDHC's wastewater guidance addresses wastewater and sludge, with requirements reflecting the discharge arrangement. It does not replace legal requirements. GFT recommends mapping trial samples to the actual material path, from process stream

through treatment and final disposition, before commissioning tests. A favourable isolated bath sample must not be presented as evidence that a mixed site discharge or sludge stream meets its applicable requirements. [S33]

For the proposed comparison, define the trial boundary before collecting data. Include recipe make-up, dyeing, planned wash-off, additional washing, correction, equipment cleaning and treatment consequences that change with the candidate. Record what remains outside the boundary. Ask the laboratory to justify sample timing and representation. A conveniently collected grab sample cannot be promoted to a batch-total load merely because its analytical result is precise.

Calculate a parameter load from its concentration and associated volume using consistent units, and retain uncertainty in both measurements. GFT recommends presenting concentration and load together. A lower concentration produced by extra dilution can accompany an unchanged or higher load; a lower volume can accompany a higher concentration. Neither result can be interpreted properly when the other quantity has been omitted from the proposed comparison.

Scale in stages governed by evidence rather than equipment availability. A laboratory trial should establish the analytical method and product response. A representative machine trial should test mixing, dosing, reproducibility and resource capture under controlled conditions. A production trial should retain normal operating variation and full release evidence. Set the acceptance criteria before each stage and preserve failed trials, since removing them would overstate confidence in the candidate route.

The proposed final decision record should state the tested product envelope, observed benefits, unresolved uncertainties, operating constraints and rollback conditions. If the candidate passes only for a narrow shade family, authorise that family rather than the whole dyehouse. Continue checking the approved route against its own evidence. Colour control then becomes resource control through a repeatable decision: retain the material identity, measure the complete cycle and release only what the evidence supports.

For a partnered wet-processing route, GFT proposes requesting the same evidence categories from the processor while stating their assurance boundary. Supplier-reported consumption should remain identified as supplier-reported; estimates should preserve their allocation basis. A missing batch meter must not be disguised by a precise per-garment conversion. The commissioning organisation can require an explanation, commission a representative trial or restrict the claim until better evidence exists. These are proposed procurement conditions, not statements that GFT already has such contractual access or that a named processor has passed this method.

The accepted shade must carry the account of every bath that made it.

CHAPTER SOURCE NOTES

S31 Springer Nature, Scientific Reports. 2022-12-26.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S37 Emerald Publishing Limited. 2019.

S32 ZDHC Foundation. 2023.

S34 European Commission. 2018-10-10.

S35 OEKO-TEX Association. 2025-01-14.

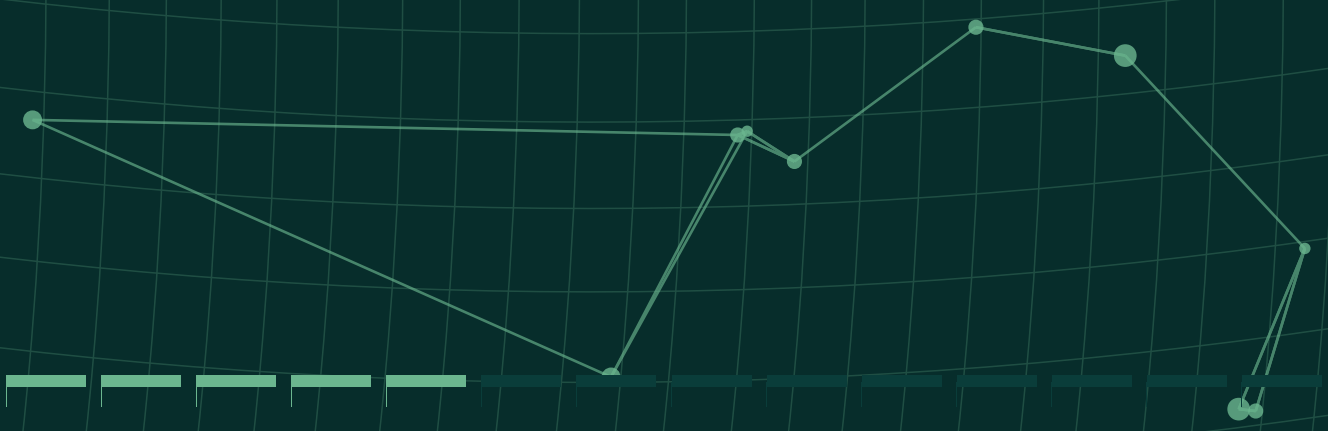
S33 ZDHC Foundation. 2024-09.

05

PART II: THE PROCESS SETS THE FLOOR / BEFORE COLOUR

Preparation sets the ceiling on dyehouse performance

Uneven or incomplete preparation propagates extra water, heat and correction through every later stage.



CHAPTER 05
DECISION TEST

Uneven or incomplete preparation propagates extra water, heat and correction through every later stage.

A dyehouse cannot control its water, chemical or thermal intensity if it treats fabric preparation as an unmeasured prologue outside the colour boundary. [S02] [S37] Every reactive, vat or direct dye bath acts on the surface delivered by desizing, scouring, bleaching and, where specified, mercerisation. [S01] [S02] Raw cotton enters wet processing with 4 to 10 percent natural non-cellulosic impurities by fibre mass, including hydrophobic waxes, pectins, proteins, hemicelluloses, mineral salts and pigments in the cuticle and primary wall. [S0501] [S0504] Woven grey cloth adds warp sizing agents applied for weaving, while knitted greige fabric carries needle oils and lubricants. [S01] [S03] When those barriers are removed unevenly, or when residual alkali, starch or hydrogen peroxide enters the dye vessel, the dyebath fails to exhaust and fix uniformly, forcing shading additions, stripping, redyeing, extra hot rinsing and stenter drying. [S16] [S37] [S0501] [S0503] For Green Future Tech Limited (GFT) in Hong Kong SAR and its Cameroon textile programme, where the sector baseline prepared on 31 January 2024 records about 95 percent of cotton fibre exported raw and 5 percent processed locally against a 2030 target of 50 percent, preparation must be metered, tested and released inside the same batch ledger as colouration. [R06] [R07] [S24]

5.1

Preparation belongs inside the colour boundary

5.2 GREY FABRIC ENTERS THE DYEHOUSE WITH A VARIABLE CHEMICAL HISTORY

Wet processing consumes 60 to 90 percent of process water in textile manufacturing, with preparation carrying a major share of hydraulic volume and organic effluent load. [S03] In the International Finance Corporation (IFC) Environmental, Health, and Safety Guidelines for Textile Manufacturing, desizing, scouring, bleaching and mercerising are sequential substrate-modification steps preparing fabrics for coloration and finishing. [S01] Woven grey fabrics arrive bearing warp sizing compounds: native or modified starches, polyvinyl alcohol (PVA), carboxymethyl cellulose (CMC), polyacrylates, galactomannans, tallow, paraffin waxes and spinning oils. [S01] [S03] Knitted greige fabrics bypass warp sizing but carry circular-knitting lubricants, needle oils and wax emulsions alongside native cotton impurities. [S01] [S0501]

Because spinning, sizing and weaving vary across suppliers, two rolls of grey cotton with identical mass per square metre can present different chemical loads to the preparation range. [S01] [S02] The European Commission Best Available Techniques (BAT) Reference Document for the Textiles Industry emphasises that water emissions, chemical handling and energy use are coupled from the moment grey fabric enters pretreatment. [S02] IFC notes that biochemical oxygen demand (BOD5) and chemical oxygen demand (COD) from desizing represent 35 to 50 percent of a mill's organic wastewater load, generating compartment COD concentrations up to 20,000 milligrams per litre (mg/L) when starch and sizing auxiliaries are washed out. [S01] Literature reviewed by VTT Technical Research Centre of Finland identifies desizing and scouring as the most chemically polluting stages of wet processing, discharging starches, waxes, fats, hemicelluloses, surfactants and strong alkali. [S03]

A process map starting at the dyebath fill valve misses the largest source of organic load and a major consumer of water and steam. [S01] [S16] In the composite-plant thermal model analysed for textile wet processing in China, Japan and Taiwan,

preparation (desizing, scouring, bleaching and mercerising), dyeing, printing and finishing account for 50 percent of plant thermal energy demand, relying on hot water and steam near 90 to 120 degrees Celsius. [S16] [S0503] Recording grey-fabric mass at receipt without logging size formulation, add-on share and impurity profile prevents separating raw-material effects from machine-control effects. [S02] [S29]

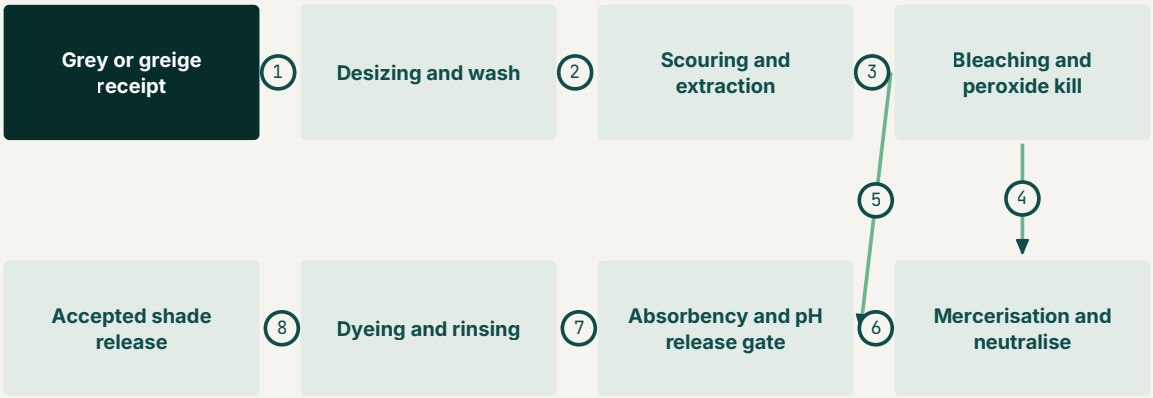
5.3 TRUNCATED DYEBATH ACCOUNTS DISGUISE UPSTREAM RESOURCE SHIFTS

Excluding preparation from a dye-per-kilogram or litre-per-kilogram claim creates an accounting distortion whenever a facility compares dyeing technologies or buys pre-prepared fabric. [S02] [S24] Under Higg Facility Environmental Module (FEM) rules, a facility manufacturing both fabric and finished products must track energy and water separately by facility type so integrated totals do not obscure process intensity. [S24] A dyehouse that buys scoured and bleached cloth (or transfers pre-prepared lots from an unmetered bay) and reports only dyebath and post-dye rinse water appears to achieve low intensity per kilogram, when desizing, caustic scouring and peroxide bleaching occurred upstream of its meter boundary. [S01] [S03] [S24]

To prevent truncation, GFT structures the wet-processing ledger as a chain of custody from grey or greige receipt to accepted shade release (**Exhibit 19**, p. 78). [S02] [S16] [S0503] Each preparation stage is a resource node consuming metered water, steam, electricity and chemicals while transforming substrate properties required by the next bath. [S02] [S16]

EXHIBIT 19 /

Preparation quality travels with the fabric into every later bath



1. Lot ID + size type
2. Starch cleared
3. Waxes removed
4. Optional route
5. Zero H2O2
6. Neutral pH
7. Wetting pass
8. RFT pass

DERIVED [S02] [S16] [S0503] Derived process and genealogy sequence from S02, S16 and S0503. Each stage records water, steam, electricity and chemical inputs alongside substrate release checks before the lot enters dyeing.

The flow architecture in **Exhibit 19**, p. 78 sets two rules for the GFT resource ledger. [S02] [S16] First, no fabric lot enters dyeing without passing an explicit absorbency and residual-chemistry release gate (`gate`) binding the preparation lot identifier to the dye-lot identifier. [S02] [S37] Second, whether a woven lot travels through the optional mercerisation branch (`mercer`) or moves directly from bleaching (`bleach`) to the release gate, all water, chemical and thermal inputs accumulated along its path remain attached to the batch record, populated from calibrated submeters rather than process diagrams. [S16] [S18] [S24] [S0503]

5.4

Absorbency is a release measurement, not a visual assumption

5.5 HYDROPHOBIC CUTICLES AND RESIDUAL PEROXIDE CAUSE UNLEVEL DYEING

A bleached cotton roll that looks white under inspection lamps can still fail in the dyebath if its hydrophilicity, residual peroxide or extractable pH varies from selvedge to centre or head to tail. [S02] [S0501] [S0503] In raw cotton, non-cellulosic impurities account for roughly 5 percent of fibre weight (4 to 10 percent range), forming a

hydrophobic cuticle where alpha-1,4-linked D-galacturonic acid pectin chains cement waxes, fats and proteins to the cellulose wall. [S0501] [S0504] Unless this sheath is stripped during scouring, dye liquor cannot wet the fibre evenly or diffuse into micropores during exhaustion. [S31] [S0501]

Conventional preparation removes warp starch by acid, oxidative or alpha-amylase desizing, and then strips the cuticle by alkaline scouring in sodium hydroxide (NaOH, 1.5 to 10 g/L in batch trials or 2 to 5 percent on fabric weight) at 90 to 100 degrees Celsius for 45 to 60 minutes with surfactants and sequestering agents. [S0501] [S0504] Harsh caustic treatment saponifies fats and emulsifies waxes, but also degrades cellulose and generates alkaline effluent with high BOD, COD and total dissolved solids (TDS). [S0501] [S0503] Enzymatic desizing with alpha-amylase at pH 5.5 to 6.5 and 30 to 60 degrees Celsius cleaves internal alpha-1,4 glycosidic bonds in starch without damaging cellulose, accounting for 30 percent of the industrial enzyme market. [S0503] Enzymatic bioscouring using pectinases, xylanases, cutinases or lipases operates at 50 to 55 degrees Celsius and pH 5.0 to 8.5, lowering effluent BOD, COD and TDS by over 50 percent compared with alkaline scouring while preserving strength. [S0501] [S0503]

Experimental comparisons confirm why absorbency must be measured quantitatively. [S0501] On 100 percent cotton single-jersey knit fabric (28 Ne, 150 g/m2) at a 1:15 liquor ratio, caustic scouring (1.5 g/L NaOH, 100 degrees Celsius, 45 minutes) achieved an average water-drop wetting time of 1.90 seconds and 3.8 percent weight loss. [S0501] Enzymatic scouring with pectate lyase (0.5 to 0.8 percent on fabric weight, 55 degrees Celsius, 60 minutes, pH 5.0 to 5.5) and synthetic surfactant achieved wetting times of 0.76 to 5.23 seconds (weight loss 2.4 to 4.3 percent), whereas 0.5 percent enzyme with 1 to 2 g/L soapnut extract averaged 4.86 seconds (3.45 to 5.77 seconds) at 3.1 to 3.8 percent weight loss, inside the 3 to 6 percent industrial window protecting bursting strength (408 kilopascals grey, 369 kilopascals caustic, and 312.50 to 383 kilopascals enzymatic). [S0501] Over-dosing soapnut raised wetting time to 10.00 seconds via surfactant-enzyme interactions, proving that bio-based recipes require batch wetting verification. [S0501]

Bleaching introduces a second hazard to downstream dyeing. [S01] [S0503] Cotton mills bleach with hydrogen peroxide (H2O2) in an alkaline bath at 90 to 120 degrees Celsius. [S0503] [S0504] IFC guidelines recommend hydrogen peroxide over chlorine bleaches because sodium hypochlorite forms adsorbable organic halogens (AOX, trichloromethane) threatening the 1 mg/L effluent guideline limit, and advise replacing poorly bioeliminable chelators (EDTA and DTPA) with biodegradable stabilisers. [S01] After peroxide bleaching, 10 to 15 percent of applied H2O2 remains; unless removed by rinsing or decomposed into water and oxygen by catalase enzyme before dyeing, residual peroxide attacks reactive dye chromophores and causes right-first-time failure. [S37] [S0503]

5.6 LABORATORY RELEASE GATES PREVENT DEFECTIVE LOTS FROM ENTERING THE DYEBATH

Because preparation defects are cheaper to correct before dye and salt are dosed, GFT treats substrate release as a mandatory laboratory gate. [S02] [S37] In a one-bath scouring and bleaching study on greige knitted cotton at 90 degrees Celsius (4 g/L scouring agent and 6 g/L of 30 percent H2O2), extending duration from 30 to 45 and 60 minutes raised whiteness from 68.07 to 73.63 and 77.04 (76.54 at 75 minutes).

[S0504] At 60 minutes, prepared cotton achieved 238 percent water absorptivity, a 2.48 second droplet diffusion time (below the 3-second GB/T 21655.1-2008 threshold), and 15-minute wicking heights of 10.4 centimetres warp and 10.1 centimetres weft. [S0504]

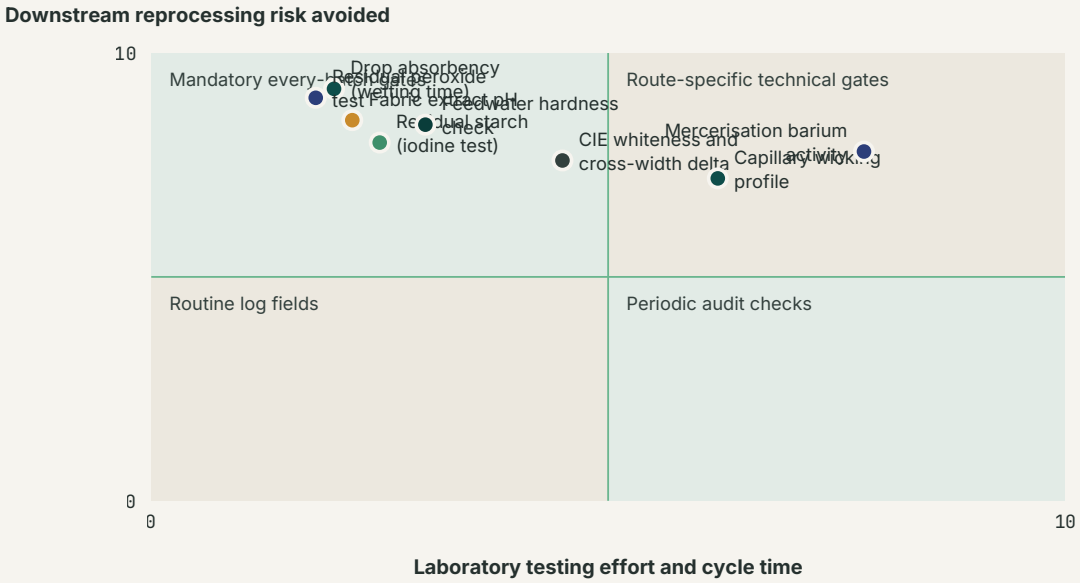
METHOD

Preparation release sampling protocol for GFT batch ledgers. Before a prepared lot enters dyeing, the laboratory samples left selvedge, centre and right selvedge swatches (at least 10 centimetres inside the edge) at the head and tail of the batch. [S02] [S0501] The technician records: (1) water-drop wetting time in seconds (mean of 10 drops from 1 centimetre height at 20 plus or minus 2 degrees Celsius and 65 percent relative humidity, AATCC 39/79, S0501); (2) residual starch rating via potassium iodide-iodine reagent on woven lots (S02, S0503); (3) extract pH (S01, S02); (4) residual H2O2 in mg/L after rinsing or catalase treatment (S0503); and (5) reflectance whiteness (CIE L* or CIE WI under D65) and cross-width delta (S31, S0501). A lot fails release if any position exceeds the wetting ceiling, shows peroxide above zero, or exhibits a cross-width pH or wetting differential causing listing. [S37] [S0501] [S0503]

To operationalise these checks, **Exhibit 20**, p. 80 positions eight preparation control variables across laboratory testing effort on the horizontal axis and downstream reprocessing risk avoided on the vertical axis. [S02] [S37] [S0501] [S0503]

EXHIBIT 20 / ILLUSTRATIVE CONTROL INDEX (0 TO 10)

A preparation release gate joins substrate, chemistry and downstream result



ILLUSTRATIVE [S02] [S37] [S0501] [S0503] Illustrative prioritisation of preparation release checks by routine laboratory testing effort (x) and downstream dyeing reprocessing risk avoided (y), based on mechanisms in S02, S37, S0501 and S0503. Thresholds must be set by product trials.

As **Exhibit 20**, p. 80 shows, fast checks in the upper-left quadrant (drop wetting time, residual peroxide, extract pH, iodine starch rating and feedwater hardness) require minutes of technician time yet intercept the main causes of unlevel dyeing, shade drift and dye hydrolysis. [S37] [S0501] [S0503] Intensive measurements in the upper-right

quadrant (wicking profiles and mercerisation barium activity or crystallinity checks) serve as route-specific gates during recipe qualification and mercerised-lot release. [S0502] [S0504] Because the coordinates in **Exhibit 20**, p. 80 are an illustrative control-design index rather than a plant regression, each facility pairs it with the field dictionary in **Exhibit 21**, p. 81 and sets numerical limits from product trials. [S02] [S37]

EXHIBIT 21 /

The preparation release record links substrate parameters to dye-lot genealogy

Release field	Stage	Method or unit	Literature reference case	Failure risk in dyeing
Fabric lot and route ID	Receipt	Alphanumeric ID	Woven gray vs knitted greige (S01)	Unmatched batch comparison
Residual size rating	Desizing	Iodine drop / TEGEWA	Amylase pH 5.5 to 6.5, 30 to 60 C (S0503)	Stiff hand, patchy dye barrier
Wetting time	Scouring	Seconds (AATCC 39/79)	0.76 to 5.23 s bioscoured; 1.90 s NaOH (S0501)	Unlevel uptake, listing
Scouring weight loss	Scouring	Percent dry mass	3.1 to 3.8% soapnut; 3 to 6% window (S0501)	Strength loss or wax residue
Residual H2O2	Bleaching	mg/L test strip or titration	10 to 15% H2O2 remains before catalase (S0503)	Reactive chromophore destruction
Whiteness and wicking	Bleaching	CIE WI; cm / 15 min	WI 77.04; wicking 10.4 cm warp (S0504)	Off-tone pastel and bright shades
Mercerisation state	Mercerising	Cl% or Barium number	Cl drops 73.12% to 63.19% in 250 g/L NaOH (S0502)	Shade depth shift between rolls
Extract pH and hardness	Final rinse	pH units; deg dH	Neutral rinse; 10 deg dH RFT optimum (S37)	Premature hydrolysis or precipitation

DERIVED [S01] [S02] [S37] [S0501] [S0502] [S0503] [S0504] Derived release-gate schema from S01, S02, S37, S0501, S0502, S0503 and S0504. Observed experimental values from cited studies illustrate measurement scales; production pass thresholds must be established per fabric specification.

Together, **Exhibit 20**, p. 80 and **Exhibit 21**, p. 81 turn BAT guidance on preparation control into an auditable table storing wetting time, extract pH, residual peroxide and whiteness beside metered litres and megajoules, with product-specific thresholds verified against first-pass colour yield. [S02] [S37] [S0501] [S0503]

5.7

Mercerisation changes later dye demand and must be costed whole

5.8 CELLULOSE SWELLING RAISES DYE UPTAKE AT A STEEP UPSTREAM CHEMICAL AND WATER PRICE

Mercerisation shows why dyehouse savings cannot be evaluated inside the dye vessel alone. [S16] [S0502] The textile electrification study notes that mercerised cotton accepts brighter, longer-lasting colours from less dye, while the treatment requires concentrated sodium hydroxide, washing and thermal energy. [S16] IFC guidelines describe the sequence: cotton reacts under tension with concentrated caustic soda, a hot-water wash removes bulk caustic, an acid bath neutralises remaining alkali, and rinses clear residual acid. [S01]

The physical chemistry behind downstream dye saving is documented in X-ray diffraction (XRD) and dyeing experiments on plain-woven cotton (160 g/m2, scoured and bleached). [S0502] Immersing cotton under tension in 250 g/L NaOH at 23 degrees Celsius for 3 minutes, washing twice at 60 to 70 degrees Celsius for 5 minutes, neutralising in 2 g/L HCl for 5 minutes and rinsing to neutrality swells the cell wall, converts native cellulose I into cellulose II, and lowers the XRD crystallinity index (CI) from 73.12 percent in original fabric to 63.19 percent (58.73 percent when caustic pre- and post-mercerisation are combined). [S0502] Because reactive dyes enter cotton through pores leading into amorphous regions, lower crystallinity and enlarged pore diameter boost dye sorption. [S0502]

In infrared dyeing (20:1 liquor ratio, 3 percent o.m.f. dye, 40 g/L NaCl and 10 g/L Na2CO3), caustic pre-mercerisation raised dye exhaustion (E%) to 85.1 percent for C.I. Reactive Red 2 (615.32 g/mol) and 65.5 percent for C.I. Reactive Red 195 (1,136.28 g/mol), while increasing fixation (F%) by 4 percent for both dyes and raising colour strength (K/S). [S0502] Pre-mercerisation in liquid ammonia at minus 40 degrees Celsius lowered crystallinity to 52.61 percent (cellulose III) but contracted pore diameter, restricting diffusion of C.I. Reactive Red 195 (56.6 percent exhaustion versus 65.5 percent for caustic) and lowering fixation. [S0502] Furthermore, caustic post-mercerisation applied *after* dyeing hydrolysed covalent ether bonds between reactive dye and cellulose, stripping 4.09 percent of fixed C.I. Reactive Red 2 from un-pre-mercerised cloth and 3.43 percent from caustic pre-mercerised cloth during 95 degrees Celsius washing (100:1 liquor ratio). [S0502]

While caustic pre-mercerisation reduces dyestuff needed for a target shade, its upstream burden is heavy. [S01] [S03] The VTT review classifies mercerising as a high-water step requiring 232 to 308 L/kg of product when dilute caustic rinses are discharged without recovery, exceeding desizing (3 to 23 L/kg), scouring (23 to 43 L/kg) and bleaching (2 to 124 L/kg). [S03] IFC guidelines specify alkali recovery and reuse from mercerising effluent, and the VTT review highlights reusing mercerising effluent in scouring and bleaching baths. [S01] [S03]

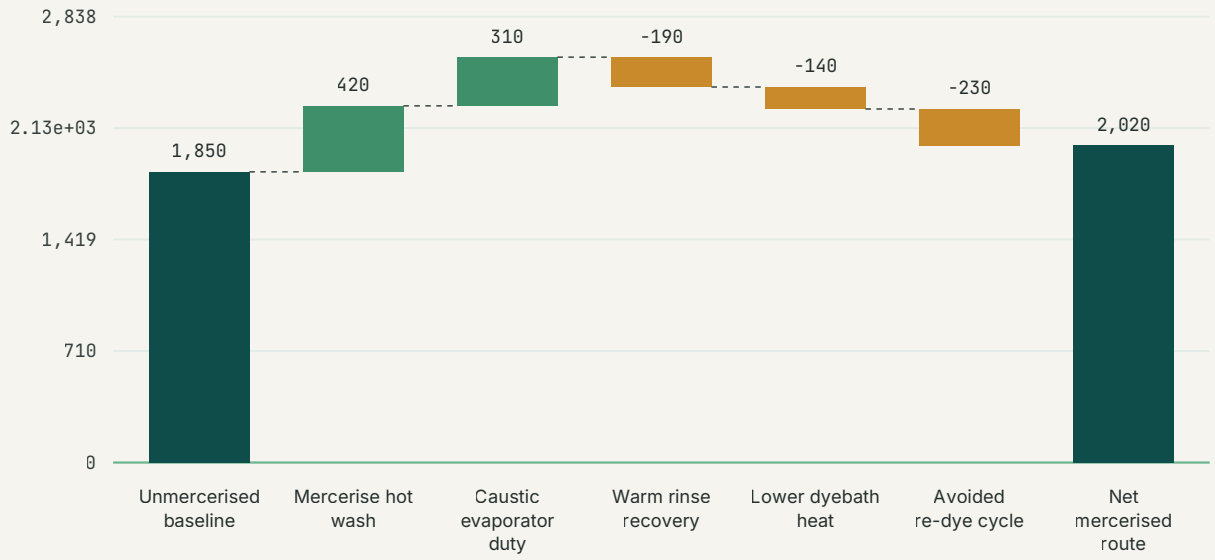
5.9 SEPARATE PHYSICAL LEDGERS PREVENT FALSE NET-SAVING CLAIMS

An engineering ledger cannot subtract saved grams of reactive dye from kilograms of sodium hydroxide, litres of wash water or megajoules of evaporator steam. [S02] [S16] Quantities with different units (L of water, kg of NaOH, kg of acid, g of dye, MJ of heat

and kWh of electricity) must be balanced in separate accounts per accepted kilogram before financial valuation applies tariffs. [S18] [S29] Even within thermal energy alone, the analyst must trace where heat is added upstream and saved downstream (**Exhibit 22**, p. 83). [S16] [S03] [S0502]

EXHIBIT 22 / MJ THERMAL ENERGY PER 100 KG ACCEPTED FABRIC (ILLUSTRATIVE)

A net mercerisation account prevents displaced savings



ILLUSTRATIVE [S16] [S03] [S0502] Illustrative single-unit thermal ledger for a 100 kg cotton woven lot, showing how mercerisation hot-wash and alkali-recovery heat duties offset downstream dyeing and reprocessing heat changes. Process relationships follow S16, S03 and S0502; water (L/kg) and caustic soda (kg/kg) are tracked in separate physical ledgers, not subtracted from MJ.

In the illustrative thermal ledger of **Exhibit 22**, p. 83, a 100 kg woven cotton lot starts at an assumed unmercerised baseline of 1,850 megajoules (MJ, or 18.5 MJ/kg, within the 12 to 25 MJ/kg woven-finishing range in S01). [S01] [S16] Caustic pre-mercerisation adds 420 MJ for hot washing at 60 to 70 degrees Celsius (S0502) and 310 MJ of evaporator steam to concentrate weak lye (S01, S16). Reusing warm alkaline wash water in scouring recovers 190 MJ (S03), while improved dye fixation cuts dyebath heat by 140 MJ (S0502) and lowers reprocessing heat by an illustrative 230 MJ (S37). The closing balance (1,850 + 420 + 310 - 190 - 140 - 230 = 2,020 MJ per 100 kg) shows a net increase of 170 MJ per 100 kg even after downstream colour gains and heat reuse are credited, proving why claiming a dyebath reduction without booking the mercerisation bay's steam, water and caustic ledgers is invalid. [S02] [S16] [S0502]

WORKED EXAMPLE

Illustrative multi-ledger balance for a 1,000 kg woven cotton lot with and without pre-mercerisation. Consider an illustrative 1,000 kg batch of woven cotton shirting (160 g/m2) dyed to a deep reactive red (3.0 percent o.m.f. in unmercerised baseline Route A, matching S0502). All numbers in this box are illustrative calculations combining mechanisms from S01, S03, S16 and S0502 to demonstrate GFT's accounting method, not observed GFT factory results.

1. **Dye and salt ledger (kilograms):** Route A uses 30.0 kg of reactive dye (3.0 percent o.m.f.) and 40.0 g/L of NaCl in a 10:1 bath (10,000 L), consuming 400.0 kg of salt. [S02] [S0502] In caustic pre-mercerised Route B, higher pore accessibility and a 4 percentage point fixation gain allow the target K/S with an illustrative 20 percent dye reduction (24.0 kg, saving 6.0 kg) and 15 percent salt reduction (340.0 kg, saving 60.0 kg). [S16] [S0502]
2. **Caustic and acid ledger (kilograms):** Route A uses 25.0 kg of NaOH in scouring (2.5 percent o.w.f.). [S0504] Without recovery, Route B requires 25.0 kg of scouring NaOH plus an illustrative 280.0 kg of NaOH for the 250 g/L mercerising bath (305.0 kg total) and 18.0 kg of HCl. [S01] [S0502] Recovering 75 percent of mercerising alkali via evaporation (210.0 kg NaOH) and routing 25.0 kg of alkaline rinse to scouring cuts net fresh NaOH makeup to 70.0 kg (25.0 + 280.0 - 210.0 - 25.0 = 70.0 kg) and acid demand to 4.5 kg. [S01] [S03]
3. **Water ledger (cubic metres):** Route A uses an illustrative 35.0 m3 (35 L/kg) in preparation and 45.0 m3 (45 L/kg) in dyeing and rinsing (80.0 m3 total, inside the 50 to 100 L/kg IFC woven range in S01). [S01] [S03] Without reuse at the lower bound of the mercerising range (232 L/kg in S03), mercerising adds 232.0 m3 while saving 5.0 m3 in post-dye rinsing (307.0 m3 total). [S03] With countercurrent washing, condensate return and rinse reuse in scouring limiting mercerising addition to an illustrative 28.0 m3 (28 L/kg) and post-dye rinsing saving 5.0 m3, Route B totals 103.0 m3 (103 L/kg), a net increase of 23.0 m3 over Route A. [S01] [S03]
4. **Decision consequence:** Mercerisation must be justified by commercial requirements for lustre, stability and strength, and engineered with caustic recovery and rinse reuse from day one. [S01] [S16] [S0502]

5.10

Batch and continuous routes need matched-product comparison

5.11 MACHINE FORM AND PROCESS INTEGRATION ALTER BASELINE CONSUMPTION

Whether preparation runs in batch vessels, semi-continuous pad-batch stations or continuous ranges changes baseline water, steam and electricity per kilogram. [S01] [S02] [S16] In batch preparation, grey or greige cloth is loaded into a jet, overflow, winch, kier or beam machine and cycled through fills, heated holds and drains for desizing, scouring and bleaching. [S01] [S02] Each drain loses sensible heat and requires fresh water to re-establish circulation, which in older winches and hank machines can exceed a 15:1 to 50:1 liquor ratio compared with 1:5 to 1:8 in modern low-liquor jet and overflow vessels. [S01] [S02]

By contrast, continuous preparation feeds stitched webs through saturators, steamers and countercurrent washing boxes at 50 to 250 metres per minute. [S01] [S02] IFC guidelines recommend three interventions: (1) combining scouring and bleaching into one step (or integrating desizing, scouring and bleaching with bleach-rinse reuse in desizing); (2) using continuous knit bleaching ranges instead of batch equipment where volume permits; and (3) applying mechanical dewatering ahead of stenters to reduce moisture and drying load. [S01] [S17]

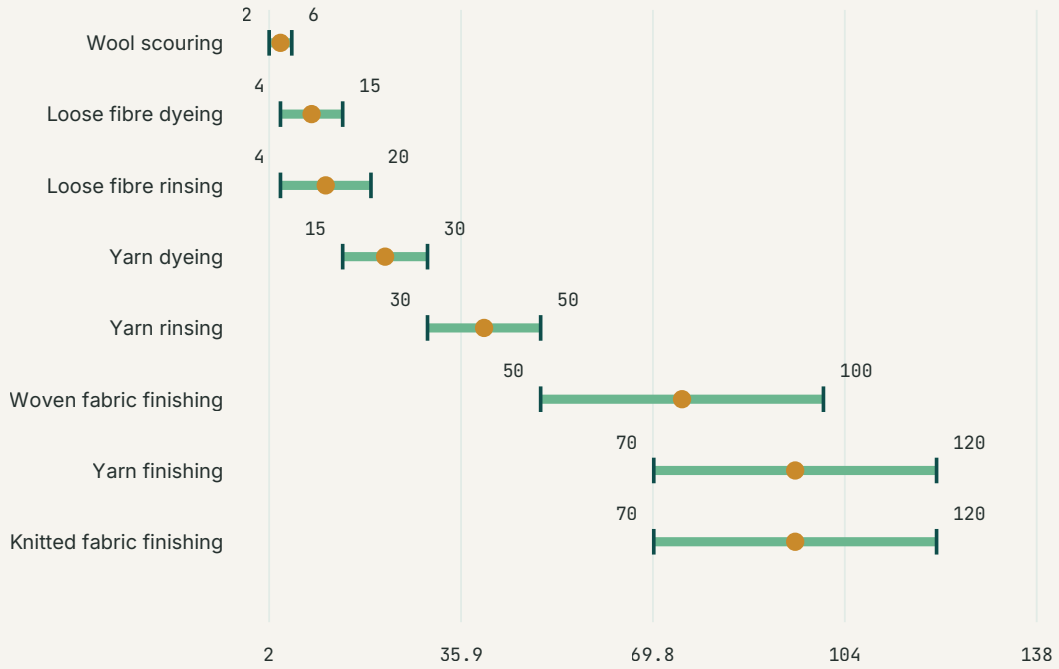
Experimental evidence confirms the potential of stage integration while highlighting its chemical boundaries. [S01] [S0504] In the combinative pretreatment study on greige knitted cotton, merging scouring and peroxide bleaching into one 90 degrees Celsius bath for 60 minutes (followed by 15-minute in-bath cationisation with 30 g/L glycidyltrimethylammonium chloride and 3 g/L NaOH) eliminated intermediate drains and re-heats while achieving 77.04 whiteness, 2.48 second wetting time and 96.74 percent salt-free reactive dye fixation for C.I. Reactive Red 195. [S0504] However, adding the cationising reagent at the start of the bath failed because alkaline peroxide degraded the reaction, proving that combined baths have strict compatibility windows. [S0504] Continuous ranges achieve low intensity per kilogram only when run lengths amortise bath charging, steamer warm-up and flushing; on short orders, batch low-liquor or cold pad-batch routes can outperform an under-loaded continuous range. [S02] [S17] [S29]

5.12 OPERATION-SPECIFIC BENCHMARKS EXPOSE THE FALLACY OF A SINGLE TEXTILE AVERAGE

Because fibre type, construction and machinery route alter process demand across wide intervals, comparing a mill's preparation and finishing intensity against one all-textile average is invalid. [S01] [S02] [S29] In Bangladesh surveys, the 18-factory PLOS study reported average groundwater intake of 164 L/kg and dyehouse water use of 136 L/kg (119 L/kg wastewater), while the World Bank study noted estimates up to 250 to 300 L/kg. [S04] [S08] When IFC disaggregates consumption by processing category in Table 3 of its guidelines, operation-specific ranges diverge (**Exhibit 23**, p. 86). [S01]

EXHIBIT 23 / LITRES PER KILOGRAM OF PRODUCT (L/KG)

Preparation and finishing benchmarks require operation-specific comparisons



SOURCED [S01] Sourced from IFC EHS Guidelines for Textile Manufacturing Table 3 (S01, citing European Commission 2003b). Midpoints are arithmetic centres of published low and high bounds. IFC notes that industry benchmarks originate from only a limited number of installations and are for comparative guidance only.

The intervals in **Exhibit 23**, p. 86 show why operation-specific accounting is mandatory. [S01] In IFC Table 3, wool scouring uses 2 to 6 L/kg (0.3 kWh/kg electrical and 3.5 MJ/kg thermal), loose-fibre dyeing uses 4 to 15 L/kg plus 4 to 20 L/kg for rinsing (0.1 to 0.4 kWh/kg electrical and 4 to 14 MJ/kg thermal), and yarn dyeing uses 15 to 30 L/kg in dyeing plus 30 to 50 L/kg in rinsing (0.8 to 1.1 kWh/kg electrical and 13 to 16 MJ/kg thermal). [S01] Full yarn finishing spans 70 to 120 L/kg, woven-fabric finishing spans 50 to 100 L/kg (0.5 to 1.5 kWh/kg electrical and 30 to 70 MJ/kg thermal), and knitted-fabric finishing spans 70 to 120 L/kg (1 to 6 kWh/kg electrical and 10 to 60 MJ/kg thermal), with dyed woven finishing below 200 L/kg and Table 4 cotton wastewater benchmarks spanning 50 to 180 L/kg across fabric routes. [S01] IFC Table 3 Footnote a warns that these benchmarks come from a limited number of installations; evaluating desizing (3 to 23 L/kg in S03), scouring (23 to 43 L/kg in S03), bleaching (2 to 124 L/kg in S03) or mercerising (232 to 308 L/kg in S03) requires sub-meters on matched fabrics. [S01] [S02] [S03] [S29]

5.13

Preparation water offers controlled reuse opportunities

5.14 STREAM SEGREGATION SEPARATES REUSABLE RINSES FROM HIGH-LOAD DESIZE LIQUOR

Preparation is both the largest generator of organic chemical oxygen demand in a cotton mill and a primary source of reusable process water, provided piping segregates effluents by contamination profile at design stage. [S01] [S02] [S03] IFC lists countercurrent washing and direct reuse of preparation and finishing water among its core water-conservation recommendations. [S01] Mixing all preparation discharges into one drain destroys that potential. [S01] [S02]

Post-desizing wash water carries degraded starch sugars, lubricants, waxes or synthetic sizes (BOD5 and COD representing 35 to 50 percent of mill organic load, up to 20,000 mg/L COD). [S01] [S03] Routing that liquor into bleaching or dyeing would consume oxidants, foul heat exchangers and re-deposit size. [S01] [S02] Instead, IFC and BAT guidance specify two pathways for desizing effluent: recovering water-soluble synthetic sizes (PVA, polyacrylates or CMC) by ultrafiltration, or routing enzymatic starch-desizing effluent to biological treatment. [S01] [S02] [S03] Conversely, later rinses after peroxide bleaching and hot washes after caustic mercerisation have low suspended solids and low polymer load, containing mainly alkalinity and heat. [S01] [S03] Bleach rinse water can cascade into scouring or desizing, while alkaline mercerising rinse water can feed scouring and bleaching baths requiring caustic soda and heat, alongside heat recovery from continuous ranges to preheat makeup water. [S01] [S03] [S17]

5.15 QUALITY GATES ON RECYCLED PREPARATION WATER PROTECT DOWNSTREAM SHADE STABILITY

Reusing preparation water without an analytical release gate risks trading a modest water saving for a severe colour-reprocessing failure. [S02] [S37] Every recycled stream re-entering wet processing must pass four checks: hardness cations, catalytic transition metals, residual oxidants or alkalis, and restricted surfactant residues. [S01] [S33] [S37]

First, calcium and magnesium hardness in makeup or recycled water interacts with scouring soaps and reactive dyes. [S01] [S37] In a full-factorial design-of-experiments study (3^2 design) on cotton dyed with red reactive dye at 5, 10 and 15 g/L across water hardness levels of 10, 40 and 70 degrees German hardness (dH), polynomial models showed that hardness and dye concentration strongly affected colour strength (K/S), lightness (L*) and colour difference, achieving right-first-time shade without reprocessing only at 10 degrees dH and 15 g/L dye. [S37] If preparation rinse water carrying calcium or magnesium extracted from cotton ash (S0501) is reused without hardness control, it shifts shade coordinates out of tolerance. [S37] [S0501] Second, trace iron and copper ions washed from grey cloth or pipework catalyse radical decomposition of hydrogen peroxide during bleaching, causing oxycellulose tendering and strength loss. [S01] [S0503] Third, any bleach rinse reused in enzymatic desizing or bioscouring must be cooled and neutralised so temperature and pH do not

deactivate alpha-amylase (pH 5.5 to 6.5, 30 to 60 degrees Celsius, S0503) or pectate lyase (pH 5.0 to 5.5, 55 degrees Celsius, S0501), and water entering dyeing must be free of residual peroxide. [S0501] [S0503]

> **WARNING**
>
> **Surfactant carry-over and restricted-substance compliance in preparation reuse.** Preparation baths rely on wetting agents, detergents and emulsifiers. [S03] [S0501] The VTT review warns that alkylphenol ethoxylates (APEOs), particularly nonylphenol ethoxylates (NPEOs), have been used in scouring and dyeing auxiliaries but degrade into toxic, persistent nonylphenols restricted under EU REACH rules. [S03] Under Zero Discharge of Hazardous Chemicals (ZDHC) Manufacturing Restricted Substances List (MRSL V3.1) rules, uploading Safety Data Sheets (SDS) for conformant products is mandatory (S32), and ZDHC Wastewater Guidelines (V2.2) test effluent for intentional use or contamination of MRSL substances (S33). Reusing preparation water containing unverified surfactants or optical brighteners from white lots into dyed lots risks ZDHC non-conformance and patchy uptake. GFT prohibits recycling brightener-bearing rinses into dyed goods and requires ZDHC MRSL conformance on all preparation auxiliaries before closing water loops. [S03] [S32] [S33]

5.16

Preparation control reduces the need for downstream correction

5.17 RIGHT-FIRST-TIME COLOUR BEGINS AT THE PREPARATION RELEASE GATE

In poorly instrumented dyehouses, the dyeing vessel is blamed for defects locked into the fabric during preparation. [S02] [S37] When a batch exits dyeing with side-to-centre shading (listing), tailing, blotches or colour difference outside CIELAB tolerance, the production response is a shading addition, soap-off or strip-and-redye cycle. [S31] [S37] Every corrective cycle consumes extra water, heat, electricity, chemicals and machine hours while producing zero additional accepted kilograms. [S37]

Even low-liquor dyeing machinery cannot compensate for an unlevel substrate. [S02] [S36] [S38] While EU BAT conclusions specify low-liquor-ratio batch dyeing (S38, 1:5 to 1:8 for cotton in rope form in S02), experimental work at a 1:6 liquor ratio shows that reactive dye fixation remains sensitive to dye structure and fibre accessibility, recording fixation rates of 84.9, 71.1 and 75.0 percent across three reactive yellow dyes (MRY-1, MRY-2 and MRY-3). [S02] [S36] [S38] Because a 1:6 bath has less liquid buffer per kilogram of cloth than a 1:15 bath, any residual starch, wax, peroxide or uneven mercerisation crystallinity (CI% variation in S0502) translates into spatial standard deviation of K/S colour strength across the fabric (20 random points per sample in S0502) and forces rework. [S36] [S0501] [S0502]

Before committing capital to new dyeing machines, GFT's engineering sequence tests whether tightening preparation control reduces dye-uptake variation and raises right-first-time (RFT) pass rates on existing vessels. [S18] [S37] Paired trials compare baseline preparation against controlled preparation (verified amylase desizing, scouring weight loss within 3 to 6 percent, catalase peroxide elimination to 0 mg/L, neutral

extract pH and wetting time below 3 seconds across left-centre-right swatches) on matched lots dyed with identical reactive recipes. [S37] [S0501] [S0503] [S0504] Only after lifting the preparation ceiling can dyebath upgrades be measured cleanly. [S02] [S18]

5.18 LINKED PREPARATION-TO-DYE GENEALOGY MAKES ROOT CAUSES AUDITABLE

For GFT's Cameroon textile programme, linking preparation records to dyeing and garment records is an industrial-structure necessity. [R06] [R07] [S24] Cameroon's sector is working to move from its baseline of about 95 percent raw cotton fibre export and 5 percent local processing (in GFT's 31 January 2024 source base, R06) toward the 50 percent local-processing target by 2030 (R07), alongside announced national restructuring and integrated-project initiatives (R08, R09, R10, R12). In GFT's operating concept, cut-make-trim (CMT) and garment finishing sit at the core while upstream spinning, weaving, knitting and wet processing involve partnered mills or phased integration. [S24]

When a dyehouse receives greige or prepared fabric from a partner mill, or transfers lots between an internal preparation range and batch dye vessels, unlinked lot numbers break root-cause analysis. [S24] [S37] If a dye lot fails RFT release and requires 80 L/kg of extra stripping and re-dyeing water, an unlinked database books the variance against the dyehouse shift, hiding the fact that a preparation roll entered with a 7.5 second wetting time on one selvedge or 12 mg/L of residual peroxide. [S37]

[S0501] [S0503] Joining prep_lot_id to dye_lot_id in the batch spine lets weekly reviews regress RFT failure rates and K/S standard deviations against incoming wetting time, extract pH, residual peroxide and water hardness. [S18] [S29] [S37]

GFT NOTE

Practical recommendation for preparation governance in GFT's Cameroon programme. 1. **Meter preparation separately from dyeing:** Install dedicated water and thermal submeters on the preparation line (desizing, scouring, bleaching and mercerising) rather than pooling wet processing on one dyehouse meter. [S01] [S18] [S24] 2. **Require a five-point substrate release certificate before dyeing:** No lot enters a dye vessel without recorded head-and-tail, left-centre-right values for drop wetting time (seconds), iodine starch rating, extract pH, residual hydrogen peroxide (0 mg/L), and CIE whiteness. [S02] [S0501] [S0503] [S0504] 3. **Evaluate enzymatic and combined-bath routes on whole-cycle metrics:** Pilot alpha-amylase desizing (pH 5.5 to 6.5, 30 to 60 degrees Celsius), pectinase bioscouring (50 to 55 degrees Celsius), one-bath scouring-bleaching, and catalase peroxide decomposition against caustic boiling by measuring preparation water, steam, effluent BOD/COD, bursting strength and dye-lot RFT pass rate. [S01] [S0501] [S0503] [S0504] 4. **Gate mercerisation on full alkali recovery and product-margin proof:** Approve caustic mercerisation only where product specifications require mercerised lustre and strength, and where countercurrent hot washing, caustic evaporation recovery and weak-rinse reuse in scouring are engineered from day one. [S01] [S03] [S16] [S0502]

The dyebath can only colour the surface that preparation has actually cleared.

CHAPTER SOURCE NOTES

S02 European Commission Joint Research Centre. 2023.

S37 Emerald Publishing Limited. 2019.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S0501 Elsevier, Heliyon. 2023-04-05.

S0504 MDPI, Molecules. 2017-12-18.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

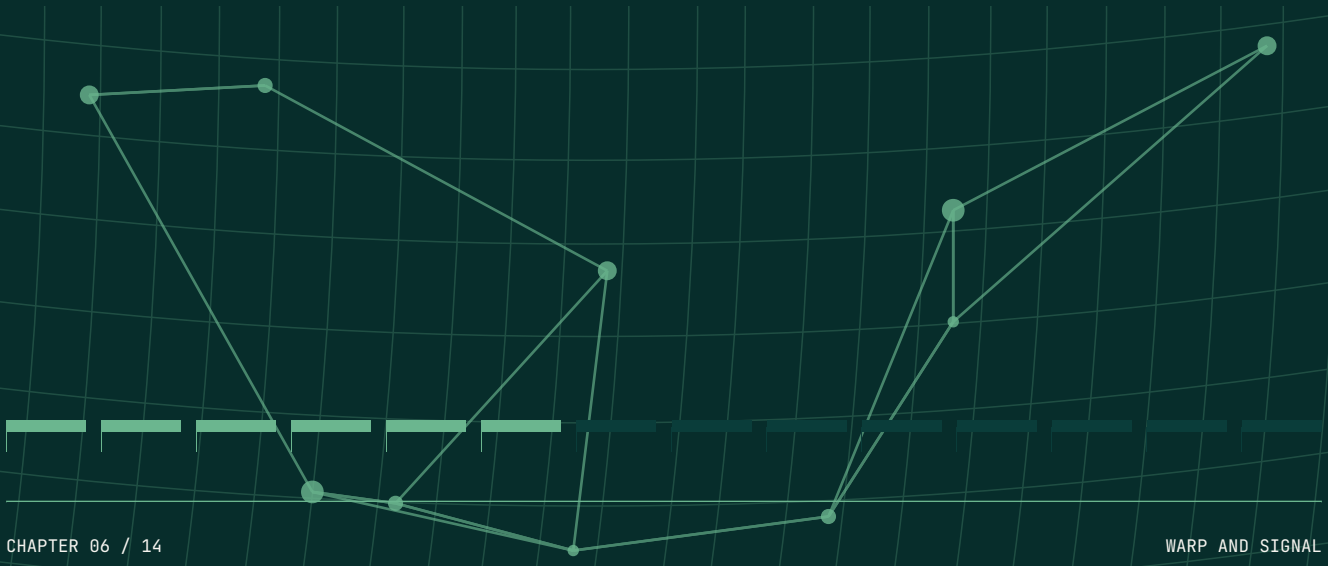
S16 MDPI, Energies. 2022-11-25.
S0503 MDPI, Molecules. 2025-10-08.
R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.
R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.
S24 Sustainable Apparel Coalition. 2022.
S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.
S18 International Organization for Standardization. 2018.
S31 Springer Nature, Scientific Reports. 2022-12-26.
S0502 MDPI, Materials. 2022-03-11.
S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.
S04 PLOS Sustainability and Transformation. 2023-07-31.
S08 2030 Water Resources Group, World Bank. 2015.
S33 ZDHC Foundation. 2024.
S32 ZDHC Foundation. 2023.
S36 Elsevier, Dyes and Pigments. 2024.
S38 European Commission. 2022-12-09.

06

PART II: THE PROCESS SETS THE FLOOR / THE DYE BATH

Low-liquor dyeing saves only when the whole cycle improves

A smaller nominal bath is an engineering opportunity whose real value depends on levelness, fixation, rinsing, throughput and reprocessing.



CHAPTER 06
DECISION TEST

A smaller nominal bath is an engineering opportunity whose real value depends on levelness, fixation, rinsing, throughput and reprocessing.

6.1

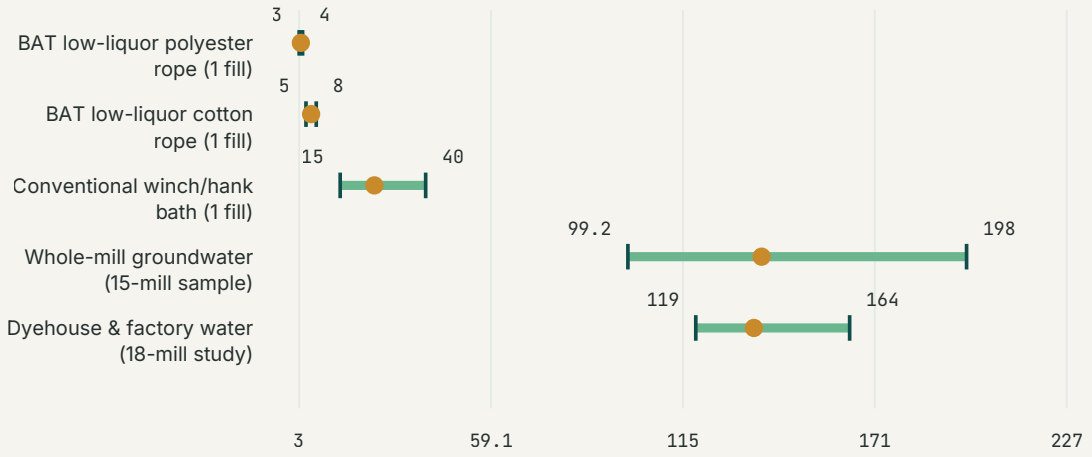
Nominal liquor ratio is not total freshwater intensity

In industrial dyehouse procurement, few numbers are quoted more frequently or misinterpreted more routinely than the nominal liquor ratio of a batch dyeing machine [S02]. Expressed as the mass of dry textile substrate to the volume of processing liquor in a single bath fill, a machine brochure figure such as 1:5 or 1:6 is often treated in feasibility spreadsheets as if a factory operating that vessel will consume 5 to 6 litres of water per kilogram of fabric produced [S02]. That arithmetic confuses the initial geometry of one vessel fill with the cumulative hydraulic duty of an entire wet-processing sequence [S01] [S02] [S24]. In a commercial dyehouse, the main dyeing bath is preceded by multi-step pretreatment (Chapter 5), followed by multiple post-dye rinsing, neutralisation and soaping baths (Chapter 7), supported by steam boilers, cooling loops and water-softening regeneration, and periodically interrupted by machine boil-outs and shade corrections [S01] [S02] [S03]. Equating nominal machine ratio with total freshwater intensity understates water intake, miscalculates effluent hydraulic capacity, and blinds management to the stages where most water is withdrawn [S01] [S04] [S24].

The gap between nominal bath ratio and site water intensity is visible in **Exhibit 24**, p. 94 as soon as engineering reference values for individual dyeing vessels are placed alongside empirical factory water balances [S02] [S04] [S05]. In the European Best Available Techniques (BAT) Reference Document for the Textiles Industry (TXT BREF), low-liquor-ratio jet and overflow dyeing machines operating on fabric in rope form carry reference fill ratios of 1:5 to 1:8 (5 to 8 L/kg in a single bath fill) for cotton substrates and 1:3 to 1:4 (3 to 4 L/kg per fill) for polyester substrates [S02]. Conventional winch and hank machines operate at wider fill ratios of 1:15 to 1:40 (15 to 40 L/kg per fill) [S02] [S31]. Yet empirical studies of operating wet-processing factories show total intensity an order of magnitude above a single low-liquor fill [S04] [S05]. Across an 18-factory sample of wet-processing mills in Bangladesh, average total groundwater extraction reached 164 L/kg of fabric, average dyehouse water reached 136 L/kg, and average wastewater discharge reached 119 L/kg [S04]. In a separate 15-mill baseline study of textile dyeing plants, extracted groundwater ranged from 99.15 L/kg to 198.20 L/kg, with a mean of 138.26 L/kg [S05], while earlier cleaner-production assessments noted by the World Bank and IFC estimated older mill consumption at up to 250 to 300 L/kg [S08].

EXHIBIT 24 / L/KG

Nominal machine liquor ratios represent a small fraction of observed dyehouse and whole-mill water intensity



SOURCED [S02] [S04] [S05] Comparison of single-fill machine liquor ratios from EU BAT reference documentation (1:3 to 1:4 polyester rope, 1:5 to 1:8 cotton rope, 1:15 to 1:40 conventional winch) with empirical dyehouse and whole-mill water intensities (99.15 to 198.20 L/kg in S05; 119 to 164 L/kg in S04).

6.2 WHY SINGLE-BATH ARITHMETIC FAILS AT THE FACTORY GATE

Four structural factors illustrated in **Exhibit 25**, p. 95 explain why the nominal machine liquor ratio diverges so sharply from whole-mill freshwater intensity (Chapter 2) [S01] [S02] [S03]:

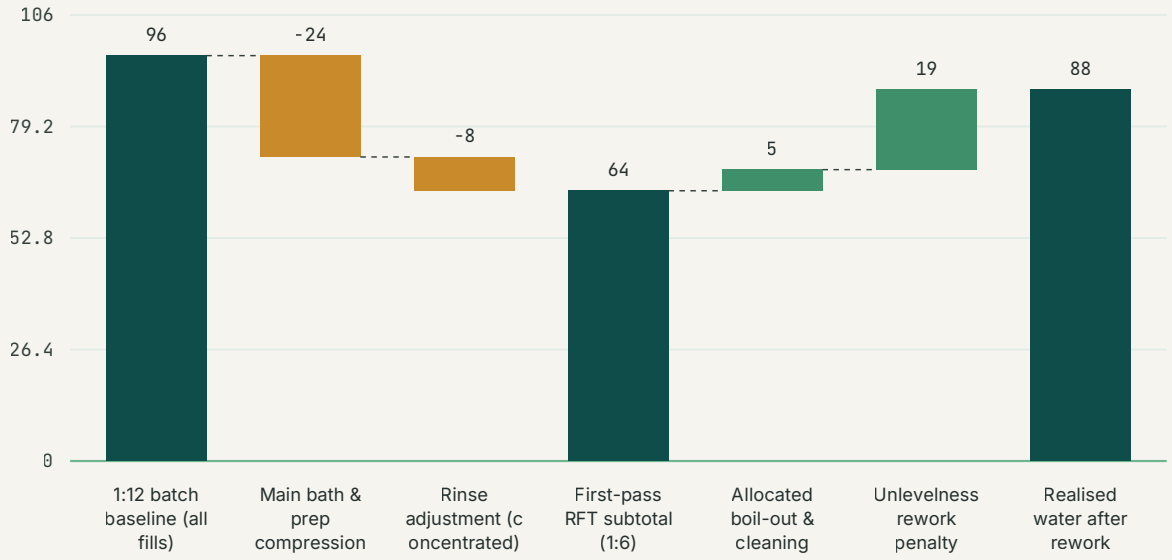
1. **Sequential bath multiplication across the recipe**: Exhaust dyeing of cellulosic fabric is a multi-bath sequence rather than a single fill [S01] [S02]. A single reactive dyeing lot of knitted cotton traverses scouring and bleaching, neutralisation, the main dyebath, cold and warm dilution rinses, one or two boiling soaping baths to remove unfixed dye, and a final softening bath [S01] [S02] [S03]. Even if every fill operates at 1:6 (6 L/kg), a recipe requiring 10 to 12 sequential fills across pre-treatment, dyeing and washing consumes 60 to 72 L/kg at the vessel inlet before auxiliary water is counted [S02] [S03].
2. **Under-loading and effective liquor-ratio drift**: Nominal liquor ratio is achieved only when the vessel is loaded at rated fabric mass and when the sump, heat exchanger and piping sit at their minimum hydrodynamic level [S01] [S02]. As the IFC guidelines emphasise, failing to match machine size to lot size forces circulation of a fixed minimum sump volume over a smaller cloth mass [S01]. In an illustrative check, if a jet machine requires a 1,000 L minimum fill for pump submergence on a rated 200 kg batch, running a 100 kg lot in that vessel pushes the effective ratio to 1:10 (10 L/kg) per fill.
3. **Non-product baths, machine boil-outs and changeovers**: Dyehouses processing varied shade palettes must clean vessels between dark and pale shades using caustic and hydrosulphite boil-outs, filter flushes and kitchen rinses that

consume freshwater while producing `0 kg` of fabric [S01] [S02] [S24]. In an accepted-kilogram ledger (Chapter 2), their water and steam sit directly in the numerator [S24] [S37].

4. **Shading additions, stripping and re-dyeing cycles**: When a low-liquor batch finishes off-shade or develops rope marks, corrective shading additions or full strip-and-redye cycles add water, steam and chemicals without adding a single kilogram to accepted output [S02] [S37].

EXHIBIT 25 / L PER ACCEPTED KG

A single reprocessing event or extra wash-off stage can erase most of a nominal low-liquor bath saving



ILLUSTRATIVE [S02] [S16] [S36] [S37] Illustrative mass-balance bridge from a conventional 1:12 exhaust baseline to a 1:6 low-liquor trial after rinsing, machine cleaning and rework adjustments, using machine ratio ranges from S02, process boundaries from S16, fixation behaviour from S36, and reprocessing logic from S37.

GFT NOTE

In GFT's resource-accounting architecture for Cameroon (Chapter 1 and Chapter 2), nominal machine liquor ratio and actual water intensity are recorded as two distinct fields in the batch genealogy and in the `footprint` and `kpi-cascade` tools [S02] [S24]. The machine record captures the **nominal fill ratio** (such as `1:6`) and the **realised main-bath fill ratio** (metered main-bath inlet litres divided by dry batch kilograms loaded) [S01] [S02]. The operational performance indicator is always **whole-cycle freshwater intake per accepted kilogram** (`L/kg accepted`), summing all metered pretreatment, dyeing, rinsing, corrective and allocated cleaning fills divided strictly by fabric mass passing quality release [S24] [S37]. No supplier or project team may multiply a brochure liquor ratio by batch count to claim a site water reduction [S02] [S24].

6.3

BAT supports low liquor as a technique, not a guaranteed percentage

Regulatory and technical reference documents endorse low-liquor-ratio machinery as a core engineering measure for batch wet processing, yet they deliberately avoid promising a single universal percentage saving across all mills, fibres and product mixes [S01] [S02] [S38]. Under Commission Implementing Decision (EU) 2022/2508 establishing the Best Available Techniques (BAT) conclusions for the textiles industry under Directive 2010/75/EU, BAT states that batch processes are carried out with low-liquor-ratio systems (citing Section 1.9.4) to reduce water and energy consumption and minimize effluent volume [S38]. The underlying TXT BREF (2023) and the IFC Environmental, Health, and Safety Guidelines (2007) similarly recommend low-liquor batch machines, semi-continuous cold pad-batch systems and continuous ranges where lot sizes and fabric constructions allow [S01] [S02]. These frameworks treat low-liquor dyeing as a conditional technique whose realised benefit depends on the baseline machine replaced, the substrate construction, the shade depth, and the accompanying dosing and circulation hardware [S01] [S02] [S38].

A dyehouse planner evaluating dyeing routes must therefore reverse the common procurement sequence: instead of picking a machine with the lowest brochure liquor ratio and forcing the product portfolio into it, engineering selection must start from the **product envelope** and **lot-size distribution**, and only then select the lowest-liquor technology capable of achieving right-first-time quality on that substrate (**Exhibit 26**, p. 97) [S01] [S02] [S37].

6.4 MATCHING DYEING ROUTE TO SUBSTRATE MECHANICS AND LOT SIZE

Different dyeing routes achieve low water and thermal intensity through distinct mechanical principles, each imposing physical boundaries on fabric tension, surface abrasion, crease formation and minimum economic run length [S01] [S02] [S03]:

- **Conventional winch and atmospheric overflow dyeing (1:15 to 1:40 bath ratio)**: The fabric rope is lifted over a reel into a large free-liquor beck [S02]. Mechanical tension is gentle, but the large liquor pool demands high water intake, heavy electrolyte additions (g/L multiplied across 15 to 40 L/kg), and high steam input [S02] [S31]. In VTT's literature review, legacy paddle and winch routes consume up to 290 m3/tonne (290 L/kg) of total process water [S03].
- **Low-liquor hydraulic jet and soft-flow overflow dyeing (1:5 to 1:8 cotton rope, 1:3 to 1:4 polyester rope)**: A circulation pump drives liquor through a nozzle or overflow weir that transports the fabric rope while exchanging liquor through the yarn interstices [S02]. Compressing the sump reduces free water, but requires rapid fabric turnover and synchronized reel-to-nozzle speed control to prevent longitudinal rope creasing, pilling on cotton knits, or elastane slippage in cotton/Lycra blends [S02] [S0602].
- **Ultra-low-liquor aerodynamic (airflow) jet dyeing (1:3 to 1:5 nominal bath ratio)**: High-velocity air from a blower propels the fabric rope through the transport tube while dye liquor is sprayed or atomised into the stream, decoupling fabric

transport from bath volume [S01] [S02]. This cuts water and steam demand, but adds blower electrical load (kWh/kg) and requires abrasion testing on hairy or low-twist cotton yarns [S01] [S02] [S16].

- **Package and beam batch dyeing (1:4 to 1:10 bath ratio)**: Stationary yarn cones, cheeses or perforated warp beams are penetrated radially by reversible high-head pumps [S01] [S02]. In IFC Table 3, yarn dyeing and rinsing consumes 40 to 300 L/kg of water, 13 to 16 MJ/kg of thermal energy, and 0.8 to 1.1 kWh/kg of electricity, reflecting the pumping power needed to overcome package resistance [S01]. Uniform winding density and flow-reversal timing are essential to prevent channelling and inside-to-outside shade rings [S01] [S02].
- **Semi-continuous cold pad-batch (CPB) dyeing**: Open-width fabric passes through a narrow padder trough (0.6 to 1.0 L/kg liquor pickup), is batched onto a plastic-wrapped roll, and rotates slowly at ambient temperature for 4 to 24 hours before wash-off [S01] [S02] [S03]. With no heated dyebath and zero inorganic salt needed for exhaustion, cold pad-batch achieves total water consumption estimated in the VTT review at 15 m3/tonne (15 L/kg) [S01] [S02] [S03], provided open-width preparation (Chapter 5), two-component alkali/dye dosing and nip pressure are uniform [S02] [S38].
- **Continuous pad-dry-pad-steam dyeing**: Open-width woven fabric is padded, dried, steamed and washed continuously [S01] [S02]. Efficiency per metre is high on long uniform runs, but trough dump losses, leader-cloth waste and washdowns make continuous ranges uneconomic on short fashion lots [S01] [S02].

EXHIBIT 26 / DERIVED SCORE (0 TO 10)

Dyeing route selection balances first-pass water and heat reduction against lot-size rigidity and control demands



DERIVED [S01] [S02] [S03] [S16] [S36] [S38] [S0602] Coordinates (0 to 10) are derived engineering scores synthesising BAT reference ratios (S02, S38), IFC energy/water ranges (S01), VTT process water comparisons (S03) and thermal demand balances (S16).

Table 1 summarises the operating envelope, resource profile, quality hazards and control prerequisites across these six routes [S01] [S02] [S03] [S16] [S38].

Dyeing route	Typical bath ratio or pickup	Primary substrates and lot profile	Water and thermal profile	Primary quality failure modes	Required engineering controls
Conventional winch / beck [S02]	1:15 to 1:40 per fill [S02] [S31]	Delicate knits, loosely woven fabrics, small lots [S02]	Up to 290 L/kg in paddle routes; high steam and salt (g/L) [S02] [S03] [S31]	Batch-to-batch shade drift from manual additions [S02]	Replacement candidate under EU BAT 2022/2508 [S38]
Low-liquor jet / overflow [S02] [S38]	1:5 to 1:8 cotton; 1:3 to 1:4 polyester [S02]	Knitted and woven cotton, blends and synthetics (100 to 1,000+ kg) [S01] [S02]	Cuts main-bath water and heat by 50 to 65 percent vs 1:15 [S02] [S16]	Rope creases, chafe marks, strike unlevelness at 1:6 [S02] [S36]	Variable-speed pump, seam detector, progressive alkali dosing [S02] [S38]
Aerodynamic airflow jet [S01] [S02]	1:3 to 1:5 nominal fill [S01] [S02]	Synthetic and cellulosic fabrics tolerant of air-jet transport [S01] [S02]	Minimal bath water and steam; higher blower power (kWh/kg) [S01] [S16]	Surface fibrillation on low-twist cotton yarns [S02]	Separate thermal (MJ/kg) and electrical (kWh/kg) metering [S01] [S18]
Package / beam batch [S01] [S02]	1:4 to 1:10 at full load [S01] [S02]	Spun yarns on cones, warp beams and open-width wovens [S01] [S02]	40 to 300 L/kg water; 13 to 16 MJ/kg heat; 0.8 to 1.1 kWh/kg power [S01]	Inside-outside shade rings from uneven winding density [S01] [S02]	Precision winding, differential pressure control, dummy spindles [S01] [S02]
Cold pad-batch (CPB) [S01] [S02] [S03]	0.6 to 1.0 L/kg pad pickup [S02]	Open-width woven and curl-controlled knitted cellulosics [S01] [S02]	Around 15 L/kg (15 m3/tonne) total water; ambient fixation; zero salt [S01] [S02] [S03]	Centre-to-selvedge shading, tailing, water spots [S02]	Uniform preparation (Chapter 5), 4:1 dosing pump, nip control [S02] [S38]
Continuous pad-steam [S01] [S02]	0.6 to 0.9 L/kg pickup + wash [S02]	Long uniform runs of woven workwear, sheeting and shirting [S01] [S02]	Low water/m on long runs; high drying heat (50 percent plant share) [S02] [S16]	Tailing across colour runs, migration during drying [S02]	Minimum lot-length gate, countercurrent wash boxes (Chapter 7) [S01] [S02]

6.5

Lower bath volume changes heat demand directly

In a textile wet-processing mill, water volume and thermal energy are physically coupled by the high specific heat capacity of liquid water (4.184 kJ/kg·K) [S01] [S16] [S17]. Every litre of freshwater drawn into a dyeing vessel at ambient supply temperature must be heated to the target process temperature (60 to 98 degrees Celsius for reactive and vat dyeing of cotton, and 130 to 150 degrees Celsius under pressure for disperse dyeing of polyester), held against radiation losses, and subsequently cooled and drained [S02] [S16] [S0603]. Reducing the mass of water per kilogram of cloth in the dyebath and hot wash baths is therefore the most direct engineering lever to cut process steam demand before any boiler upgrade or heat-recovery exchanger is specified (Chapter 8 and Chapter 11) [S01] [S16] [S17].

Techno-economic modelling of textile wet processing demonstrates the scale of this thermal burden [S16]. Across a typical composite textile plant, wet-processing preparation, dyeing, printing and finishing together account for 50 percent of total thermal energy demand, while another 35 percent of fuel energy is lost during steam generation in boilers and distribution through steam piping [S16]. Within the woven-fabric model analysed by Hasanbeigi and colleagues (2022), the dyeing and washing stage alone requires 5.9 GJ/tonne (5.9 MJ/kg) of thermal energy at temperatures up to 150 degrees Celsius, alongside 4.5 GJ/tonne (4.5 MJ/kg) in preparation and 4.7 GJ/tonne (4.7 MJ/kg) in drying and finishing [S16]. Empirical process benchmarks compiled by the IFC (Table 3) show wider thermal envelopes across batch routes: yarn dyeing and rinsing consumes 13 to 16 MJ/kg of thermal energy (0.8 to 1.1 kWh/kg electricity), loose-fibre dyeing consumes 4 to 14 MJ/kg (0.1 to 0.4 kWh/kg electricity), knitted-fabric finishing consumes 4 to 24 MJ/kg (0.2 to 1.5 kWh/kg electricity), and woven-fabric finishing consumes 5 to 45 MJ/kg (0.2 to 2.3 kWh/kg electricity) [S01].

6.6 SENSIBLE HEAT PHYSICS AND THE STEAM-DISTRIBUTION MULTIPLIER

Consider the sensible-heat balance of a batch dyeing vessel (Q = m * c_p * delta_T) used in industrial process-heating analysis [S17]. Because dry cotton fibre has a specific heat capacity below one-third that of liquid water (4.184 kJ/kg·K), and because water mass exceeds fibre mass by a factor of 5 to 20, between 90 and 96 percent of the sensible heat required to raise a dyebath to temperature goes into heating the water rather than the textile [S02] [S16] [S17]:

- **Heating a single bath from 30 C to 80 C (delta_T = 50 K) at 1:12 vs 1:6**: At 1:12 (12 kg water per 1 kg cotton), heating the water absorbs 12 * 4.184 * 50 = 2,510 kJ (2.51 MJ/kg), while heating 1 kg of cotton absorbs roughly 68 kJ (0.07 MJ/kg), giving an illustrative net sensible heat duty of 2.58 MJ/kg per fill [S02] [S16] [S17]. Compressing that fill to 1:6 cuts water sensible heat in half to 1,255 kJ (1.26 MJ/kg), lowering total bath sensible heat to 1.32 MJ/kg - a direct reduction of 1.26 MJ/kg (48.8 percent) at the heat exchanger [S02] [S17].

- **Repeating the saving across hot soaping baths**: Reactive dyeing on cotton requires one or two hot washing or boiling soaping baths (85 to 95 C) to desorb unfixed dye (Chapter 7) [S02] [S31] [S36]. Reducing two hot wash baths (30 C to 90 C, delta_T = 60 K) from 1:12 to 1:6 saves an additional 1.51 MJ/kg per bath at the vessel [S02] [S17].
- **The 35 percent boiler and steam-network loss multiplier**: Because 35 percent of fuel input in a steam-heated mill is lost in boiler generation and steam distribution (S16), saving 1.0 MJ of net process heat at the dyeing vessel avoids approximately 1.0 / (1 - 0.35) = 1.54 MJ of primary boiler fuel [S16] [S17].

6.7 THERMAL-TO-ELECTRICAL TRADE-OFFS AND ELECTRIFICATION CAUTIONS

Whole-cycle verification under ISO 50001 (S18) and specific energy consumption (SEC) benchmarking (S29) requires metering both steam and electricity across the entire cycle rather than booking a theoretical main-bath heat credit [S17] [S18] [S29]:

1. **Heating ramp rate and hold duration**: In a 1:5 or 1:6 bath, lower thermal mass raises temperature faster (C/min), requiring programmable ramp control to prevent unlevel dye strike [S02] [S36]. Conversely, if poor levelness or bath reconstitution extends the hot hold from 60 to 90 minutes (S0603), radiation and pump heat losses accumulate across the added dwell time [S17] [S0603].
2. **Circulation pump and blower electricity (kWh/kg)**: High-turnover circulation pumps and airflow blowers run continuously across pretreatment, dyeing, rinsing and cooling [S01] [S02]. Trial ledgers must log steam (MJ/kg) and electricity (kWh/kg) in separate columns so a thermal saving does not hide an electrical penalty [S01] [S18] [S29].
3. **Grid-carbon caution on direct electric heating**: Replacing steam coils with direct electric heating eliminates the 35 percent steam-system loss in S16, but on a carbon-intensive grid it can raise short-term CO2 emissions (for example, adding 442 kt CO2/year in China's 2030 dyeing scenario in S16 Table 8) unless paired with high-COP heat pumps or low-carbon power (Chapter 10) [S16] [S25]. Lowering bath volume first cuts heat demand regardless of heat supply [S16] [S17].

6.8

Dosing and circulation become more critical as slack falls

Why do many dyehouses purchase 1:5 or 1:6 low-liquor machines and then run them at 1:10 or 1:12 on the shop floor? The reason is chemical and hydrodynamic slack [S02] [S36]. Cutting water volume per kilogram of cloth by half or two-thirds while holding shade depth (% o.w.f.) constant doubles or triples the concentration (g/L) of dyestuff, electrolyte, alkali and auxiliaries in the bath [S02] [S31] [S36]. Simultaneously, the free water cushioning the fabric rope shrinks and bath turnover time through the injection zone shortens [S02]. Minor errors in dye selection, salt solubility, alkali dosing rate, pH control or water hardness immediately trigger aggregation, hydrolysis or unlevelness [S36] [S37] [S0601] [S0602].

6.9 DYE MOLECULAR STRUCTURE AND FIXATION DIVERGENCE AT 1:6 LIQUOR RATIO

Commercial reactive dyes cannot be dropped interchangeably into a 1:6 recipe with a standard assumed saving [S36]. Experimental work on reactive dye structure and eco-friendly dyeing (S36, *Dyes and Pigments*, 2024) tested three reactive yellow dyes (MRY-1, MRY-2 and MRY-3) at a 1:6 liquor ratio and found fixation rates of 84.9 percent for MRY-1, 71.1 percent for MRY-2, and 75.0 percent for MRY-3 [S36].

That 13.8 percentage-point gap at 1:6 between MRY-1 (15.1 percent unfixed) and MRY-2 (28.9 percent unfixed) directly governs whole-cycle performance (Chapter 4 and Chapter 7) [S36]. Nearly double the unfixed dye mass remains concentrated inside a 6 L/kg bath with MRY-2, forcing extra dilution and boiling soaping baths to pass wet fastness and requiring more initial dyestuff to hit target K/S [S31] [S36]. Low-liquor capability is therefore a joint property of the **machine** and the **dye molecular architecture**, never of the vessel alone [S31] [S36].

6.10 ELECTROLYTE CONCENTRATION, PH WINDOWS AND COMPETING ALKALINE HYDROLYSIS

In conventional cotton reactive dyeing, negatively charged cotton fibres repel anionic dye molecules (D-SO3-), requiring 20 to 80 percent o.w.f. (30 to 100 g/L) of Glauber's salt (Na2SO4) or sodium chloride (NaCl) to drive exhaustion, followed by alkali (Na2CO3 or NaOH) to deprotonate cellulose (Cell-O-) for covalent fixation [S01] [S31] [S0601] [S0602]. When the liquor ratio is compressed from 1:20 to 1:6, two chemical sensitivities intensify simultaneously [S02] [S36]:

1. **pH strike sensitivity and CIELAB coordinate drift**: In an evaluation of reactive dyeing on 100 percent knitted cotton (150 g/m2, 28 Ne yarn, dyed with 1 percent Remazol Yellow RR and 50 g/L Glauber's salt at 45 to 60 C, S0601), varying dyebath pH across pH 2, 4, 6, 8, 10 and 12 shifted colour strength (K/S), CIELAB coordinates (L*, a*, b*, C*, h) and wash/rubbing fastness (ISO 105-C06, ISO 105-X12, ISO 105-E04) [S0601]. Because a 6 L/kg bath has one-third the buffer volume of an 18 L/kg bath, bolus alkali addition causes local pH spikes (pH > 11.5) and unlevel surface strike before circulation equalises the rope [S02] [S0601].
2. **Alkali over-concentration and accelerated dye hydrolysis**: During fixation, cellulose reaction competes with hydroxyl (OH-) attack in water, which permanently hydrolyses the dye [S31] [S0602]. In a response-surface-methodology (RSM) optimization on cotton/Lycra knit (95/5 blend, 190 g/m2, dyed with Reactive Red 239 across 50, 60 and 70 C, 50, 65 and 80 g/L salt, and 5, 10 and 20 g/L Na2CO3, S0602), raising sodium carbonate from 10 g/L to 20 g/L accelerated dye hydrolysis instead of fibre bonding and reduced K/S [S0602]. Compressing bath volume from 1:12 to 1:6 without recalibrating g/L alkali and using progressive dosing curves drives hydrolysis up and fixation down [S36] [S0602].

6.11 WATER HARDNESS, ELECTROLYTE AGGREGATION AND THE RIGHT-FIRST-TIME (RFT) CLIFF

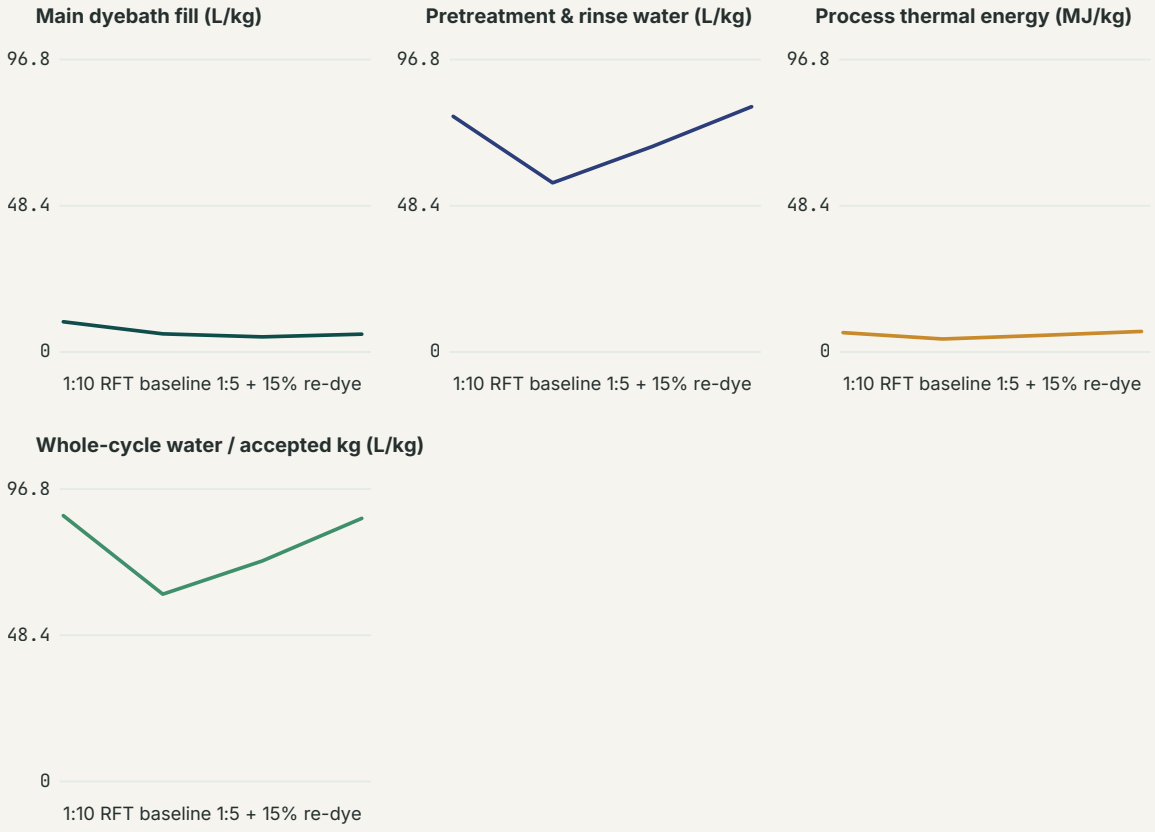
Reduced bath volume also magnifies calcium (Ca2+) and magnesium (Mg2+) hardness interference (Chapter 5) [S37]. In a 3^2 factorial Design of Experiments (DoE) study on 100 percent woven cotton (130 g/m2) dyed with Drimaren Red HF-CD (5, 10 and 15 g/L) across water hardness of 10, 40 and 70 degrees dH at 60 C (S37), regression models explained R^2 = 0.9950 for K/S, R^2 = 0.9995 for L*, R^2 = 0.9941 for a*, R^2

= 0.9421 for b*, and R^2 = 0.9410 for delta E [S37]. Rising hardness (40 to 70 degrees dH) precipitated carbonates and hydroxides and aggregated dye molecules, depressing K/S and pushing delta E out of tolerance; hitting right-first-time (RFT) shade (K/S = 22.84, delta E = 0.25) required 10 degrees dH softened water and 15 g/L dye [S37].

To verify that low-liquor compression preserves levelness (**Exhibit 27**, p. 102), dyehouses must measure multi-point CIELAB delta E and the **Relative Unlevelness Index (RUI)** across 400 to 700 nm (RUI < 0.2 excellent, RUI < 0.5 commercial pass, S0604), booking any shading addition or re-dye directly into the batch resource numerator [S37] [S0604].

EXHIBIT 27 / L/KG AND MJ/KG PER ACCEPTED KG

Paired batch trials must track main-bath water, wash-off water, thermal load and rework together



ILLUSTRATIVE [S16] [S31] [S36] [S37] Illustrative four-panel comparison across a 1:10 baseline and three 1:5 to 1:6 low-liquor outcomes per accepted kilogram, constructed from thermal balances in S16, reactive wash-off requirements in S31 and S36, and right-first-time reprocessing penalties in S37.

CASE

Worked illustrative calculation: Whole-cycle mass and energy balance for a paired 500 kg cotton reactive dyeing trial [S02] [S36] [S37]

Consider an illustrative paired trial on 500 kg lots of 180 g/m2 combed cotton single-jersey knit dyed to a 3.0 percent o.w.f. reactive shade (84.9 percent fixation benchmarked from MRY-1 at 1:6 in S36) against a 1:10 baseline [S02] [S16] [S36] [S37]:

1. **Regime A - Illustrative baseline 1:10 exhaust batch (100 percent RFT, 500 kg accepted)** [S02] [S37]:
2. **Water & salt**: Main bath at 10 L/kg (5,000 L) with 60 g/L Glauber's salt (300 kg) and 15 g/L soda ash (75 kg), plus 8 pretreatment/rinse baths at 1:10 (40,000 L) = 45,000 L (90.0 L per accepted kg) [S02] [S31] [S0602].
3. **Energy**: Net process steam heat of 6.20 MJ/kg (3,100 MJ, aligned with 5.9 MJ/kg in S16) and pump power of 0.45 kWh/kg (225 kWh) [S01] [S16].
4. **Regime B - Illustrative controlled 1:6 low-liquor batch with progressive alkali dosing and 10 degrees dH water (100 percent RFT, 500 kg accepted)** [S02] [S36] [S37]:
5. **Water & salt**: Main bath at 6 L/kg (3,000 L), salt at 65 g/L (195 kg, -35 percent), progressive soda ash at 12 g/L (36 kg), plus 8 pretreatment/rinse baths at 1:7 average (28,000 L) = 31,000 L (62.0 L per accepted kg, saving 28.0 L/kg or 31.1 percent) [S02] [S36] [S0602].
6. **Energy**: Net steam heat drops to 4.25 MJ/kg (2,125 MJ, saving 1.95 MJ/kg net heat and 3.00 MJ/kg boiler fuel after 35 percent steam losses in S16), while pump power rises slightly to 0.52 kWh/kg (260 kWh) [S01] [S16] [S17].
7. **Regime C - Illustrative uncontrolled 1:5 trial with bolus alkali and 40 degrees dH water (RUI > 0.6, strip and re-dye; 460 kg accepted after 40 kg trim loss)** [S37] [S0604]:
8. **Total inputs**: Initial cycle (37,500 L) plus 6 corrective strip/re-dye/soap baths at 1:7 (21,000 L) consumes 58,500 L water, 150 kg extra salt, 2.90 MJ/kg extra steam, and 6.5 hours of extra machine time [S02] [S37].
9. **Realised intensity (460 kg accepted)**: 58,500 L / 460 kg = 127.2 L per accepted kg (+37.2 L/kg worse than the 1:10 baseline) and 8.32 MJ per accepted kg [S24] [S37].

6.12

Dyebath reuse needs recipe and contamination gates

Cleaner-production frameworks including the IFC guidelines (S01) and the EU TXT BREF (S02) identify **reconstitution and reuse of exhausted dyebaths** to conserve water, residual heat and unexhausted chemicals [S01] [S02]. Instead of draining the hot bath to effluent, spent liquor is pumped to an insulated holding tank, assayed for residual dye and auxiliary concentrations, replenished with makeup stock, and reused on a subsequent lot [S01] [S02] [S0603]. In practice, however, dyebath reuse is governed

by chemical thermodynamics: **what works reliably for non-reacting disperse or acid dyes on synthetics fails rapidly for covalently reacting dyes on cotton unless strict analytical and contamination gates are enforced** [S01] [S02] [S36] [S0603].

6.13 WHY DISPERSE AND ACID BATHS RECONSTITUTE MORE CLEANLY THAN REACTIVE BATHS

Feasibility depends first on whether the dyeing cycle alters the chemical state of unfixed dye in the residual liquor [S02] [S31] [S0603]:

- **Non-reacting disperse dyeing of polyester**: Disperse dyes are non-ionic molecules that partition into polyester at 130 C under weak acid (pH 4.5 to 5.5) without covalent reaction; residual dye in the exhausted bath remains chemically active [S02] [S0603]. In microwave high-temperature (130 C) disperse dyeing of polyester across 1 to 6 percent o.m.f. (S0603), filtering the spent 2 percent o.m.f. bath, assaying residual dye spectrophotometrically, replenishing dispersing agent and dyestuff to 2 percent o.m.f., and readjusting pH yielded commercially viable shades (K/S from 2.59 to 8.28 in the reused bath versus 4.08 to 8.85 in the first bath for dye 11d) and wash/perspiration fastness of 4 to 5, with pilot disperse baths reused over 30 times [S0603]. Even there, S0603 recorded a key operational trade-off: target uptake in the reused bath required extending dyeing time from 60 minutes to 90 minutes (+50 percent vessel dwell time) [S0603].
- **Reactive dyeing of cotton and cellulosic blends**: Alkaline fixation (pH 10.5 to 11.8) converts unfixed reactive dye (15.1 to 28.9 percent at 1:6 in S36) into **hydrolysed dye** (D-OH), which cannot bond to cotton in a later batch yet absorbs at the same visible wavelength (lambda_max) as active dye [S31] [S36] [S0602]. Pumping a spent reactive bath directly into the next cotton lot stains the cloth with inactive dye, inflates wash-off demand (Chapter 7), and introduces 30 to 80 g/L of salt (14,540 mg/L TDS in S31), residual alkali, cotton waxes and lint [S02] [S31] [S37].

6.14 MANDATORY QUALITY AND ANALYTICAL GATES FOR DYEBATH REUSE

GFT's engineering rules prohibit unmonitored pump-back reuse and require five operational gates before releasing any reconstituted bath [S01] [S02] [S33]:

1. **Particulate filtration and extractables ceiling**: Spent liquor must pass fine filtration to remove fibre lint, oligomers (which precipitate below 80 C) and hardness precipitates (S37, S0603) [S02] [S37] [S0603].
2. **Assay of active versus hydrolysed species**: Multi-wavelength UV-Visible spectrophotometry suffices for non-reacting disperse or acid baths (S0603) [S02] [S0603]. For reactive baths, reuse is restricted either to **brine recovery after decolourisation** (Chapter 9) or to single-shade dark campaigns capped by a strict purge limit (for example, 3 to 5 cycles maximum) [S01] [S02] [S36].
3. **Conductivity, pH and hardness reconciliation**: In-line conductivity (measuring residual g/L salt), hardness (degrees dH per S37) and pH must be reset before adding fresh dye; alkaline reactive baths must be neutralised to pH 6 to 7 so fresh dye does not strike or hydrolyse upon injection (S0601, S0602), deducting the resulting neutralisation salt from fresh electrolyte makeup [S02] [S31] [S37] [S0601] [S0602].

4. **Shade-sequence routing discipline**: Reused baths retaining trace colour are restricted to repeating the identical dark SKU or stepping lighter-to-darker within compatible trichromatic recipes to prevent metamerism and delta E failure [S01] [S02] [S37].

5. **Separate physical and financial ledger accounting**: In GFT's ledger (Chapter 2 and Chapter 13), avoided freshwater (L/kg) and retained heat (MJ/kg) are booked alongside reuse-loop pumping/filtration electricity (kWh/kg), acid makeup (g/kg), lab assays, and extended cycle time (60 to 90 min in S0603), combining them financially only via explicit unit prices in the unit-economics tool [S18] [S24] [S29] [S0603].

6.15

Novel chemistry graduates through laboratory, pilot and production gates

Because conventional cotton reactive dyeing consumes 20 to 80 percent o.w.f. inorganic salt, academic and supplier studies frequently propose alternative chemistries to eliminate salt, compress liquor ratios or replace water [S02] [S31] [S36] [S0604]:

- **Biodegradable organic salt/alkali exhaustion dyeing (TNA)**: In *Scientific Reports* (S31, 2022), trisodium nitrilotriacetate (TNA at 50 g/L, pH 10.95) replaced inorganic salt and alkali across five reactive dyes (2 percent o.w.f.) on bleached cotton knit, improving exhaustion (%E) and fixation (%T) and reducing residual dyebath COD, BOD and TDS for Reactive Yellow 145 from 23,871 to 269 mg/L (99 percent), 6,300 to 160 mg/L (97 percent), and 14,540 to 487 mg/L (97 percent), respectively [S31].

- **Tailored high-fixation reactive dyes at 1:6 liquor ratio**: Synthesising reactive structures with higher substantivity and bifunctional reactivity (MRY-1 reaching 84.9 percent fixation at 1:6 versus 71.1 percent for MRY-2 in S36) reduces unfixed dye directly in existing low-liquor machines [S36].

- **Non-aqueous reverse-micellar solvent dyeing**: In *Polymers* (S0604, 2023), cotton knit (175 g/m2) was dyed salt-free in an octane / n-octanol medium using non-ionic surfactant Tergitol 15-S-12 (10:1 solvent-to-cotton ratio at 70 C), achieving high K/S, low RUI (400 to 700 nm) and wash fastness of 4 to 4-5 [S0604].

6.16 WHY LABORATORY BEAKER METRICS CANNOT BE PASTED INTO A FACTORY BUSINESS CASE

GFT's evidentiary rules (Chapter 1 and Chapter 14) prohibit pasting laboratory percentages such as 99 percent COD reduction (S31) or zero-salt solvent dyeing (S0604) into a Cameroon factory business case for four engineering reasons [S31] [S0604]:

1. **Beaker liquor ratios versus industrial vessels**: The S31 trials were conducted on 2 g fabric swatches at a 1:40 **liquor ratio** (80 mL bath, where 50 g/L TNA equals 200 percent o.w.f. chemical mass) [S31]. A beaker at 1:40 does not prove solubility, circulation or cost on a 500 kg rope lot at 1:6 [S02] [S31].

2. **Single-bath sample versus composite wash-off effluent**: The 99 percent COD and 97 percent TDS reductions in S31 (Table 6) measured the residual RY 145 dyebath sample after biodegradation, not composite factory effluent containing desizing/scouring loads (Chapter 5) and multi-stage soapings (Chapter 7) [S02] [S03] [S31].
3. **Toxicology, MRSL conformance and chelation risk**: Any novel organic salt or auxiliary must pass ZDHC MRSL V3.1 screening (which mandates Safety Data Sheets under S32), REACH limits (S34), and ZDHC Wastewater Guidelines V2.2 (S33) [S32] [S33] [S34]. Aminopolycarboxylate chelators like NTA/TNA must be checked for heavy-metal mobilisation, regulatory status and biological treatment compatibility (Chapter 9) [S02] [S31] [S32] [S33].
4. **Solvent recovery and ATEX containment**: Running 10:1 liquid octane/octanol at 70 C (S0604) requires explosion-proof (ATEX) sealed machines, >99.5 percent closed-loop distillation recovery, and VOC abatement (S02) so a water reduction does not become a hydrocarbon hazard [S01] [S02] [S0604].

METHOD

GFT four-stage graduation gate for dyeing recipes, auxiliaries and low-liquor cycles

No low-liquor compression, dyebath reuse loop or novel auxiliary chemistry may enter GFT's production baselines or financial projections until it passes four sequential verification gates (Chapter 14) [S18] [S32] [S33] [S37]:

1. **Gate 1 - Chemical safety, SDS and MRSL pre-screening (Desk & Lab Entry)** [S32] [S33]:
2. Collect mandatory Safety Data Sheets (SDS) and ZDHC MRSL V3.1 conformance certificates (S32), REACH checks (S34), aquatic toxicity and effluent-plant compatibility data (S01, S33) [S01] [S32] [S33] [S34].
3. **Hard stop**: Reject any product lacking a valid SDS, failing ZDHC MRSL, or requiring uncontained volatile hydrocarbon solvents [S02] [S32].
4. **Gate 2 - Laboratory factorial window and local-water stress test (100 g to 1 kg lab dyeing)** [S37] [S0602]:
5. Run a factorial DoE (S37, S0602) at the **target industrial liquor ratio** (1:5 to 1:8, never 1:40) across site water hardness (10 to 40+ degrees dH per S37) and pH perturbations (S0601), measuring %E, %F, K/S, delta E, RUI (400 to 700 nm per S0604), and ISO 105-C06, X12, E04 and B02 fastness (S31, S0601) [S31] [S36] [S37] [S0601] [S0604].
6. **Hard stop**: Hold in lab if delta E > 0.8, RUI > 0.5, or fastness falls below 4 (3-4 dark wet rub) [S37] [S0601] [S0604].
7. **Gate 3 - Pilot vessel hydrodynamic and effluent trial (15 kg to 50 kg sample jet/package)** [S18] [S29]:
8. Run 3 consecutive pilot lots metering total water (L/kg), steam (MJ/kg), electricity (kWh/kg), and composite effluent pH, COD, BOD, TDS and ZDHC parameters (S18, S29, S31, S33) [S18] [S29] [S31] [S33].
9. **Hard stop**: Recalibrate liquor ratio upward if rope marks, cavitation or extra hot washes negate main-bath savings [S02] [S36].
10. **Gate 4 - Paired production batch trial and whole-cycle unit-cost sign-off (300 kg to 1,000 kg shop floor)** [S24] [S29] [S37]:
11. Run 5 to 10 paired production lots on matched fabric, logging whole-cycle L/accepted kg, MJ/accepted kg, kWh/accepted kg, g/accepted kg, cycle minutes, RFT %, and net cost in the unit-economics ledger (Chapter 2, Chapter 13 and Chapter 14) [S18] [S24] [S29] [S37].
12. **Hard stop**: Promote to master recipe only when RFT %, fastness, ZDHC wastewater compliance and net unit resource/cost per accepted kilogram all pass simultaneously [S18] [S33] [S37].

By binding machine selection, bath volume, thermal balances, dosing precision, dyebath reuse and novel chemistry to a single whole-cycle ledger denominated in accepted kilograms, a dyehouse converts low-liquor dyeing from a brochure slogan into a disciplined engineering system [S02] [S18] [S37]. Yet even when the dyebath itself achieves high fixation at a low liquor ratio, the batch is only halfway to the stenter: the

unfixed dye and electrolyte remaining in the cloth must still be removed in post-dye washing and rinsing (Chapter 7), where poor mass-transfer design can easily squander every litre saved in the dye vessel [S01] [S02] [S03].

A smaller dyebath is an engineering promise; only the final rinse meter and the quality release desk can certify that the water was actually saved.

CHAPTER SOURCE NOTES

S02 European Commission Joint Research Centre. 2023.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S24 Sustainable Apparel Coalition. 2022.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

S04 PLOS Sustainability and Transformation. 2023-07-31.

S05 MDPI, Textiles. 2022-09-28.

S31 Springer Nature, Scientific Reports. 2022-12-26.

S08 2030 Water Resources Group, World Bank. 2015.

S37 Emerald Publishing Limited. 2019.

S16 MDPI, Energies. 2022-11-25.

S36 Elsevier, Dyes and Pigments. 2024.

S38 European Commission. 2022-12-09.

S0602 Wiley, Journal of Engineered Fibers and Fabrics. 2019-04-12.

S18 International Organization for Standardization. 2018.

S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.

S0603 MDPI, Molecules. 2018-11-16.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

S25 World Bank. 2025-06-25.

S0601 Royal Society of Chemistry, RSC Advances. 2022-10-26.

S0604 MDPI, Polymers. 2023-10-21.

S33 ZDHC Foundation. 2024.

S32 ZDHC Foundation. 2023.

S34 European Commission. 2018-10-10.

GREEN FUTURE TECH

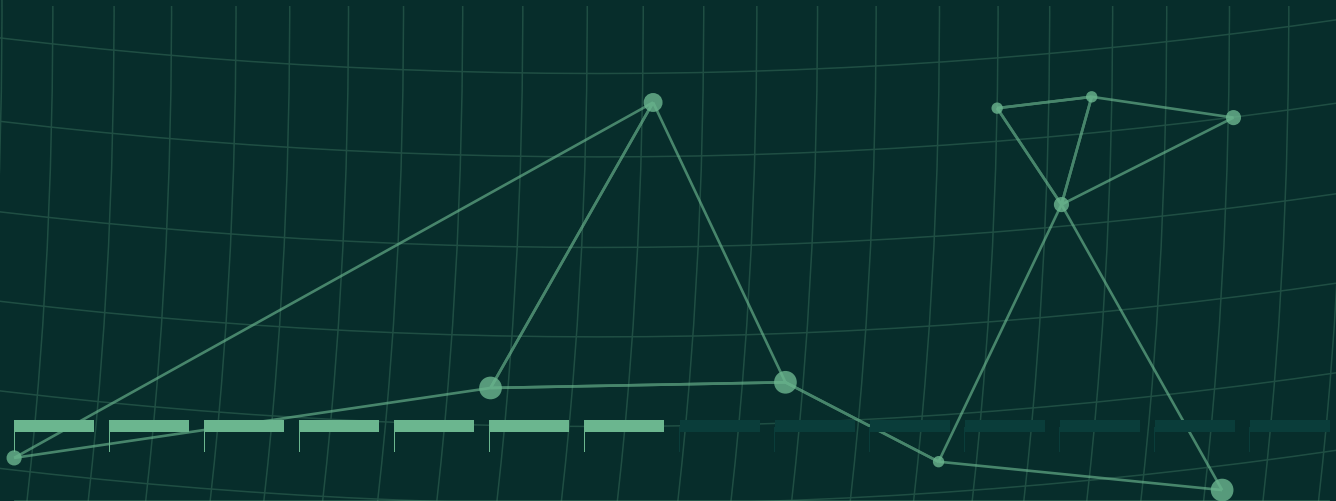
LIMITED / HONG KONG SAR

07

PART II: THE PROCESS SETS THE FLOOR / WASHING AND SEPARATION

Rinsing should be designed as mass transfer, not a water quota

The correct rinse is the minimum flow that reaches the specified residual-chemistry endpoint with acceptable colour and fabric quality.



CHAPTER 07
DECISION TEST

The correct rinse is the minimum flow that reaches the specified residual-chemistry endpoint with acceptable colour and fabric quality.

Rinsing and post-dyeing wash-off consume more wet-processing water than the dyebath itself whenever operators run fixed bath counts or timed overflow valves instead of managing solute removal as a mass-transfer process. [S01] [S02] [S0702] In cellulosic reactive dyeing and denim finishing, water enters after chemical reaction or surface abrasion to desorb, diffuse and dilute unfixed hydrolysed dye, inorganic electrolytes, residual alkali, oxidants and reducing agents out of the fibre interior and boundary layer until the substrate meets colour-fastness rules and the discharged liquor satisfies effluent limits. [S31] [S36] [S0701] [S0702] Treating that separation duty as an arbitrary water quota, such as three 10-minute overflows or six machine fills regardless of shade depth, liquor carryover or incoming water quality, wastes freshwater, overloads effluent plants with hydraulic volume and burns steam to heat rinse water that performs little additional extraction. [S01] [S02] [S0702] Designing rinsing as mass transfer means specifying a residual-chemistry endpoint on both the textile and the wash bath, minimising liquor carryover through mechanical extraction, routing wash water countercurrently so the cleanest water contacts the cleanest cloth, matching control logic to continuous or batch machines, and accounting simultaneously for rinse water, heat and garment-level denominators. [S01] [S02] [S17] [S38]

7.1

Rinsing has a measurable job

7.2 UNFIXED DYE AND RESIDUAL ELECTROLYTES DEFINE THE SEPARATION LOAD

Textile wet processing uses water in two distinct physical roles: first as a reaction and transport medium during preparation and dyeing, and second as a separation solvent during washing and rinsing. [S01] [S02] [S03] Across the literature reviewed by VTT Technical Research Centre of Finland, wet processes account for 60 to 90 percent of total water used in textile manufacturing, and washing follows almost every chemical step across desizing, scouring, bleaching, mercerising, dyeing, printing and garment finishing. [S01] [S03] When a factory tracks only total groundwater extraction, which averaged 164 L/kg of fabric (with 136 L/kg in the dyehouse and 119 L/kg of wastewater generated) across surveyed Bangladeshi mills in one study and spanned 99.15 to 198.20 L/kg (averaging 138.26 L/kg) across long-term mill baselines in another, it conceals how much water is consumed not by the colouration reaction, but by multi-stage wash-off sequences designed to strip unfixed chemicals from the fibre. [S04] [S05] [S0702]

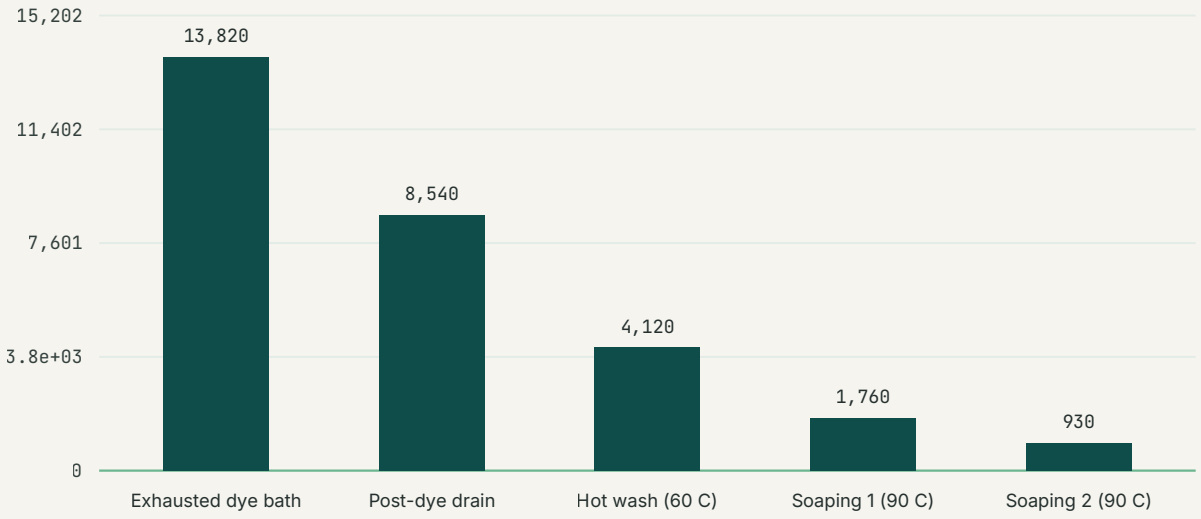
The magnitude of the post-dyeing separation duty is set by the fixation efficiency of the preceding dyebath. [S31] [S36] [S0702] In conventional exhaustion dyeing of cotton knit fabrics with reactive dyes, covalent bond formation with cellulose hydroxyl groups competes with alkaline hydrolysis in the bath. [S31] [S36] [S0702] Even when inorganic electrolyte (sodium chloride or sodium sulphate at 10 to 80 g/L depending on shade depth) and alkali (sodium carbonate or sodium hydroxide) are dosed to overcome cotton's negative surface potential and drive exhaustion, reactive dye fixation on conventional cotton remains between 50 and 70 percent. [S31] [S0702] Consequently, 30 to 50 percent of the applied dye remains in the fibre pores and residual liquor as unfixed or hydrolysed dye alongside the entire mass of added salt and alkali. [S0702] Even in low-liquor-ratio batch dyeing at a 1:6 liquor ratio, structured reactive yellow dyes

(MRY-1, MRY-2 and MRY-3) recorded fixation rates of 84.9, 71.1 and 75.0 percent respectively, leaving 15.1 to 28.9 percent of the dye load to be removed during wash-off. [S36]

If hydrolysed reactive dye or loose indigo pigment remains trapped in inter-yarn capillaries or adsorbed weakly on the fibre surface when fabric advances to drying, it migrates during laundering, perspiration contact or rubbing. [S31] [S37] [S0702] Rinsing therefore performs two coupled mass-transfer tasks: first, diluting and displacing the concentrated electrolyte and alkali in the retained liquor so that internal ionic strength and pH drop rapidly, reversing the substantivity that holds hydrolysed dye against the cellulose wall; and second, supplying thermal kinetic energy and a concentration gradient at the fibre-liquor interface so hydrolysed dye diffuses out of the amorphous regions of cotton into the bulk wash water. [S02] [S31] [S0702]

EXHIBIT 28 / ELECTRICAL CONDUCTIVITY (US/CM)

Measured wash-off stages show progressive dilution of electrolyte load



SOURCED [S0702] Values reported in S0702 Table 7 for regular dark-shade (Black, 5 percent owf reactive dye, 80 g/L salt, 20 g/L soda ash) exhaustion dyeing and sequential post-dyeing wash-off stages on 160 g/m2 cotton knit fabric. Corresponding TDS falls from 9,780 to 1,150 mg/L and COD falls from 1,842 to 497 mg/L across the same five stages.

The stage-by-stage measurements in **Exhibit 28**, p. 111 show how solute extraction progresses across a dark-shade reactive wash-off sequence on 160 g/m2 cotton knit fabric. [S0702] In the regular black dyeing route (5 percent on weight of fabric reactive dye with 80 g/L sodium chloride and 20 g/L sodium carbonate), the exhausted dyebath recorded pH 11.8, total dissolved solids (TDS) of 9,780 mg/L, electrical conductivity (EC) of 13,820 uS/cm, chemical oxygen demand (COD) of 1,842 mg/L, five-day biochemical oxygen demand (BOD5) of 870 mg/L and dissolved oxygen (DO) of 2.69 mg/L. [S0702] After bath drain (pH 10.7, TDS 4,740 mg/L, EC 8,540 uS/cm, COD 1,354 mg/L, BOD5 590 mg/L), a 10-minute hot wash at 60 degrees Celsius lowered EC to 4,120 uS/cm and TDS to 3,620 mg/L (COD 1,017 mg/L, pH 8.5), the first 10-minute boiling soaping at 90 degrees Celsius reduced EC to 1,760 uS/cm and TDS

to 1,910 mg/L (COD 823 mg/L, pH 7.6), and the second 10-minute boiling soaping at 90 degrees Celsius brought the final bath to EC 930 uS/cm, TDS 1,150 mg/L, COD 497 mg/L, BOD5 210 mg/L and pH 7.3. [S0702]

7.3 ENDPOINTS MUST BE SPECIFIED BY PRODUCT AND CHEMICAL ROUTE RATHER THAN BATH COUNT

Exhibit 28, p. 111 shows why a fixed rule of three hot washes and two soapings for every batch is an accounting failure disguised as standard procedure. [S02] [S0702] In the same study, when cotton knit was pre-cationised with 3-chloro-2-hydroxypropyl trimethyl ammonium chloride (EPTMAC) to eliminate salt addition during dyeing, the dark-shade dyebath entered wash-off at pH 10.9 with TDS 3,650 mg/L, EC 6,300 uS/cm, COD 1,186 mg/L and BOD5 480 mg/L. [S0702] Following drain (TDS 1,940 mg/L, EC 3,140 uS/cm, COD 923 mg/L) and one hot wash (TDS 1,060 mg/L, EC 1,120 uS/cm, COD 527 mg/L, pH 8.23), a single soaping step at 75 degrees Celsius reached a cleaner final bath (TDS 540 mg/L, EC 490 uS/cm, COD 319 mg/L, BOD5 140 mg/L, pH 7.3) than the conventional route achieved after two boiling soapings at 90 degrees Celsius, while maintaining wash and rubbing fastness ratings of 4 to 5 and cutting total water use across five shades from 53 to 89 L/kg down to 41 to 57 L/kg (a 20 to 37 percent reduction). [S0702]

Similarly, when salt-free and alkali-free exhaustion dyeing of cotton with C.I. Reactive Yellow 145 (RY 145) and C.I. Reactive Red 195 (RR 195) used tetra-sodium-1,3,6-naphthalenetrisulfonate (TNA) instead of inorganic salt and soda ash, followed by cold rinsing, hot rinsing and boiling soaping with 2 g/L non-ionic detergent at a 1:50 wash liquor ratio for 15 minutes, dyebath effluent COD, BOD and TDS fell by 99, 97 and 97 percent for RY 145 (from 2,212 mg/L COD, 410 mg/L BOD and 41,220 mg/L TDS down to 29 mg/L COD, 11 mg/L BOD and 1,120 mg/L TDS) and by 99, 99 and 97 percent for RR 195 (from 2,175 mg/L COD, 365 mg/L BOD and 42,630 mg/L TDS down to 31 mg/L COD, 5 mg/L BOD and 1,089 mg/L TDS), while achieving ISO 105-C06 wash fastness and ISO 105-X12 dry and wet rubbing fastness of 4 to 5. [S31]

A rinse specification must therefore define the target state at the end of washing rather than prescribing a fixed water quota. [S02] [S31] [S0701] In GFT's engineering grammar, every washing step is specified by four boundary variables: 1. **Entering contaminant mass load on the textile**, set by preceding bath concentration, fixation efficiency (71.1 to 84.9 percent at 1:6 liquor ratio in S36, or 50 to 70 percent in S0702) and retained liquor volume per kilogram of wet cloth. [S01] [S36] [S0702] 2. **Substrate release specification**, comprising neutralised fabric extract pH, zero residual oxidant or reductant where carryover harms downstream steps, and verified wash fastness (ISO 105-C06), rubbing fastness (ISO 105-X12) and CIELAB colour difference (dE) within tolerance. [S31] [S37] [S0702] 3. **Final rinse bath residual threshold**, expressed as maximum electrical conductivity (EC), TDS, optical absorbance (or Pt-Co colour) and pH in the final compartment or drain before unloading. [S0701] [S0702] 4. **External discharge and reuse compliance boundary**, matching the segregated or composite stream against Zero Discharge of Hazardous Chemicals (ZDHC) Wastewater Guidelines (V2.2) or national limits such as Tunisian standards NT 106-002 and NT 106-003 (pH 6.5 to 9, TSS 400 mg/L, COD 1,000 mg/L, EC 7,000 uS/cm, TDS 5,000 mg/L). [S33] [S0701]

7.4

Countercurrent flow reduces dependence on fresh water

7.5 CONTACT ORDER AND MECHANICAL EXTRACTION GOVERN DILUTION EFFICIENCY

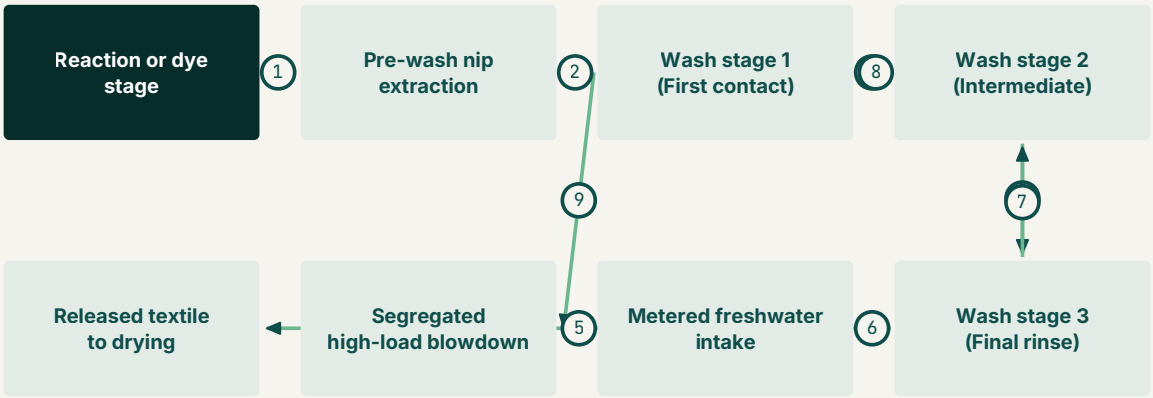
In a single-stage dilution bath or open overflow rinse, fresh water mixes immediately with the concentrated liquor carried by the wet textile. [S01] [S02] Once bulk bath concentration equilibrates with interstitial liquor inside the yarn, adding more water to that same mixed vessel yields diminishing mass-transfer returns because overflow leaves at low solute concentration while the fibre boundary layer remains poorly stripped. [S01] [S02] Both the International Finance Corporation (IFC) Environmental, Health, and Safety Guidelines for Textile Manufacturing and the European Commission Best Available Techniques (BAT) Reference Document (BREF) and BAT Conclusions (EU 2022/2508) identify two physical interventions as the primary defence against excessive rinse water demand: **mechanical liquor extraction between stages** and **countercurrent washing**. [S01] [S02] [S38]

Mass-transfer arithmetic explains why mechanical extraction and countercurrent flow multiply each other's effect. [S01] [S02] In staged washing without chemical reaction, single-stage dilution depends on the ratio of wash water volume (V_w, L/kg dry cloth) to retained carryover liquor (V_c, L/kg dry cloth). [S01] [S02] When cotton drains by gravity alone, capillary retention holds 1.2 to 1.8 L/kg (120 to 180 percent wet pick-up). [S01] [S02] Reducing V_c before and between wash stages via high-extraction nip rollers, vacuum slots on continuous ranges or centrifugal hydro-extraction in batch systems to 0.6 to 0.8 L/kg (60 to 80 percent wet pick-up) cuts the mass of dissolved salt, alkali and unfixed dye carried into the next wash stage by half before any rinse water is added. [S01] [S02] [S38]

Countercurrent washing then reverses the direction of fluid contact across sequential compartments or batch fills. [S01] [S02] Fresh water enters only at the final polishing stage where the cloth is nearly clean; effluent leaving that final stage carries only trace residuals (S0701, S0702) and cascades backward into preceding stages against the direction of fabric travel until the most contaminated liquor exits the first post-process wash stage at high solute concentration and elevated temperature. [S01] [S02] [S0701] [S0702]

EXHIBIT 29 /

Countercurrent washing directs the cleanest water to the cleanest contact



1. Saturated cloth
2. Dewatered cloth
3. Stripped cloth
4. Low-residual cloth
5. Clean cloth via nip
6. Cleanest water
7. Cascade (low TDS)
8. Cascade (medium TDS)
9. Warm concentrate

DERIVED [S01] [S02] [S0701] Derived from IFC EHS Guidelines countercurrent washing and mechanical liquor extraction principles (S01), EU Textiles BREF washing system designs (S02) and stage-wise rinse cascading in denim finishing (S0701).

As shown in **Exhibit 29**, p. 114, feeding fresh water exclusively to the final rinse stage preserves a positive concentration driving force ($C_{\text{fibre}} - C_{\text{bath}} > 0$) across every compartment while discharging a single concentrated blowdown from Stage 1. [S01] [S02] [S0701] That geometry cuts freshwater intake per kilogram of cloth and delivers the discharged load in a smaller, warmer stream suited for heat recovery or membrane treatment. [S01] [S02] [S17]

CASE

Worked mass-transfer comparison: parallel drain-and-fill versus mechanical extraction and countercurrent cascading. Consider an illustrative 100 kg cotton lot leaving an exhaustion bath with retained liquor at 50 g/L dissolved electrolyte (TDS), where the release gate requires residual electrolyte in retained fabric liquor to fall below 0.80 g/L (800 mg/L, comparable to final soaping in S0702). [S01] [S02] [S0702] 1. **Route A (Gravity drain-and-fill without nip extraction or reuse):** Gravity draining leaves $V_c = 1.5\text{ L/kg}$ (150 L carrying 7.5 kg salt). Adding $V_w = 6.0\text{ L/kg}$ (600 L illustrative salt-free water) per fill gives a stage dilution factor of $V_c / (V_c + V_w) = 1.5 / 7.5 = 0.20$. Residual concentration falls to 10.0 g/L after Stage 1, 2.0 g/L after Stage 2 (failing release), and 0.40 g/L after Stage 3, requiring **3 fills and 18.0 L/kg (1,800 L) of fresh water**. 2. **Route B (Mechanical extraction to 0.70 L/kg, parallel fresh fills):** Dewatering between stages cuts V_c to 0.70 L/kg (3.5 kg salt carryover). Two parallel fills of $V_w = 4.9\text{ L/kg}$ each yield a stage factor of $0.70 / 5.6 = 0.125$, reducing concentration to 6.25 g/L in Stage 1 and 0.78 g/L (< 0.80 g/L) in Stage 2, requiring **9.8 L/kg (980 L) of fresh water**. 3. **Route C (Mechanical extraction to 0.70 L/kg plus 3-stage countercurrent cascade):** With wash-to-carryover ratio $R = V_w / V_c$ across $N = 3$ ideal countercurrent stages, $(R^{N+1} - 1) / (R - 1) = 50 / 0.78 = 64.1$ gives $R \approx 3.76$, or $V_w = 3.76 \times 0.70 = \mathbf{2.63\text{ L/kg}}$ (263 L total fresh water). Even applying a 1.5x stage-efficiency allowance for internal fibre diffusion, the cascade uses **3.95 L/kg**, cutting freshwater demand by nearly 80 percent relative to Route A. [S01] [S02]

7.6 CASCADING BATCH RINSES REQUIRE EXPLICIT CHEMICAL-COMPATIBILITY RULES

Batch machines can approximate countercurrent flow by holding later, cleaner rinses in buffer tanks to serve as makeup water for earlier washes or main baths of subsequent batches, provided incompatible chemistries are segregated. [S01] [S02] [S0701] A 2026 process-based assessment of industrial denim finishing in Tunisia evaluated six wet-finishing stages across seven weekly production campaigns: dyeing preparation (25 degrees Celsius, 15 minutes), dyeing, enzymatic stonewashing (pumice, cellulase and acetic acid at 50 degrees Celsius, 30 to 45 minutes), hypochlorite bleaching (45 degrees Celsius, 15 to 20 minutes), sodium metabisulfite neutralisation (40 degrees Celsius, 10 minutes) and soaping (2 to 5 g/L soap at 75 degrees Celsius, 10 minutes), each followed by two two-minute fresh-water rinses (Rinse 1 and Rinse 2). [S0701]

Across all stages, Water Quality Index (WQI) values fell by up to roughly 70 percent after two rinses. [S0701] Stonewashing main baths reached 4,500 to 4,700 mg/L COD, colour above 5,000 Pt-Co and total suspended solids (TSS) up to 1,290 mg/L, but two rinses lowered TSS to 300 mg/L (below the 400 mg/L Tunisian NT 106-003 sewer limit) and COD below 1,000 mg/L. [S0701] Bleaching TSS dropped tenfold from 300 mg/L (Sample 4) to 35 mg/L after two rinses, while neutralisation main baths (pH 4 to 6, TDS near 4,800 mg/L, EC above 8,000 uS/cm) diluted to compliant ionic levels by Rinse 2, and dyeing WQI improved from 116.61 (unsuitable) to 65.72 (Rinse 1) and 33.66 (Rinse 2, good). [S0701] Redirecting Rinse 1 to the next main bath and Rinse 2 to the next Rinse 1 conceptually cuts freshwater intake by nearly two-thirds across two-rinse steps, subject to two mandatory GFT gates: **dyeing rinses are excluded from**

direct dye-bath reuse without decolourisation to prevent shade drift, and **multi-cycle pilot runs must verify salt accumulation** before permanent piping is approved. [S0701]

7.7

Continuous and batch washing need different control logic

7.8 CONTINUOUS WASHING RANGES CONTROL COMPARTMENT FLOW, TURBULENCE AND NIP EXPRESSION

As documented in IFC guidelines and the European TXT BREF, continuous ranges and batch vessels operate under distinct hydrodynamic regimes. [S01] [S02] In continuous open-width or rope ranges running at 50 to 250 m/min, cloth resides in each wash box for only seconds, so boundary-layer resistance controls extraction. [S01] [S02] High-efficiency continuous washers (S01, S02, S38) rely on three engineering controls: 1. **Through-flow turbulence and spray impingement:** Horizontal wash boxes, vertical double-laced washers with spray bars, and vacuum drum washers force liquor through the fabric (through-flow rather than surface over-flow) to strip interstitial solutes rapidly. [S01] [S02] 2. **Inter-stage high-extraction nips:** Pneumatic or swimming squeeze rollers and baffles isolate each compartment so dirty liquor is pressed back into compartment k while cleaner liquor cascades backward from compartment $k+1$ to k. [S01] [S02] 3. **Speed-synchronised feed and stop interlocks:** Under BAT conclusions (EU 2022/2508), fresh-water flow into the final compartment is proportioned to fabric mass throughput (kg/min), and automatic valves shut off water and steam whenever the range stops. [S01] [S02] [S38]

7.9 BATCH WASHING MACHINES REQUIRE SEQUENCED DRAINS, FILLS AND INTERMEDIATE EXTRACTION

In batch winches, jets, airflow vessels, package machines and garment drums, the textile stays inside one vessel coated with concentrated mother liquor. [S01] [S02] [S0704] Cracking open a drain valve while running a continuous overflow inlet allows fresh water to short-circuit across the sump to the drain. [S01] [S02] Both IFC and EU BAT guidelines therefore replace batch overflow rinsing with **sequenced fill, circulate, drain and extract cycles** (drain-and-fill) coupled with centrifugal extraction or reuse tanks. [S01] [S02] [S38]

Batch operations also incur a major water and heat burden from **washing the dyeing machines between batches** to prevent shade cross-contamination. [S0704] At Croatian cotton knitwear producer Galeb d.d. in Omis, operating four batch dyeing vessels (two 100 kg, one 300 kg and one 500 kg capacity), inter-batch machine cleaning required filling each vessel with 40 degrees Celsius tap water, heating to 98 degrees Celsius for 30 minutes, draining and flushing with 20 degrees Celsius water for 5 minutes, consuming up to **26,000 m3 of drinking water per year** across two shifts. [S0704] Treating composite wastewater through hybrid pretreatment and ultrafiltration (ZW1 hollow-fibre and PT 5 kDa flat-sheet membranes) yielded decolourised permeate (pH 8.2, EC 1,925 uS/cm, and hardness of 67.7 mg/L CaCO3 vs 214 mg/L in tap water) suitable for machine washing. [S0704] GFT therefore meters machine boil-outs separately from fabric wash-off and schedules light-to-dark shade sequences to minimise inter-batch boil-outs. [S02] [S37] [S0704]

7.10 BENCHMARKING MUST NEVER POOL CONTINUOUS AND BATCH WASHING INTENSITIES

Pooling continuous and batch washing into one factory L/kg KPI violates normalisation discipline. [S01] [S02] [S24] [S29] In IFC Table 3, loose-fibre rinsing uses 4 to 20 L/kg (after 4 to 15 L/kg in dyeing), yarn rinsing uses 30 to 50 L/kg (exceeding the 15 to 30 L/kg used in yarn dyeing), woven finishing spans 50 to 100 L/kg, and knitted finishing spans 70 to 120 L/kg. [S01] Even on a single batch machine type (S0702), conventional reactive dyeing water rose from 53 L/kg for Pink (0.133 percent dye) and 55 L/kg for Yucca (0.94 percent dye) to 69 L/kg for Navy (2.89 percent dye), 72 L/kg for Wine (2.86 percent dye) and 85 to 89 L/kg for Black (5.0 to 5.78 percent dye) because dark shades required extra boiling soaping. [S0702] GFT stratifies washing KPIs by five mandatory keys: **equipment class** (S01, S02, S38), **substrate form and areal density** (g/m2, S01, S0702), **dye and fixation chemistry** (S31, S36, S0702), **shade depth bracket** (S02, S0702), and **cycle purpose** (first-pass wash-off, rework wash-off or machine boil-out, S37, S0704).

7.11

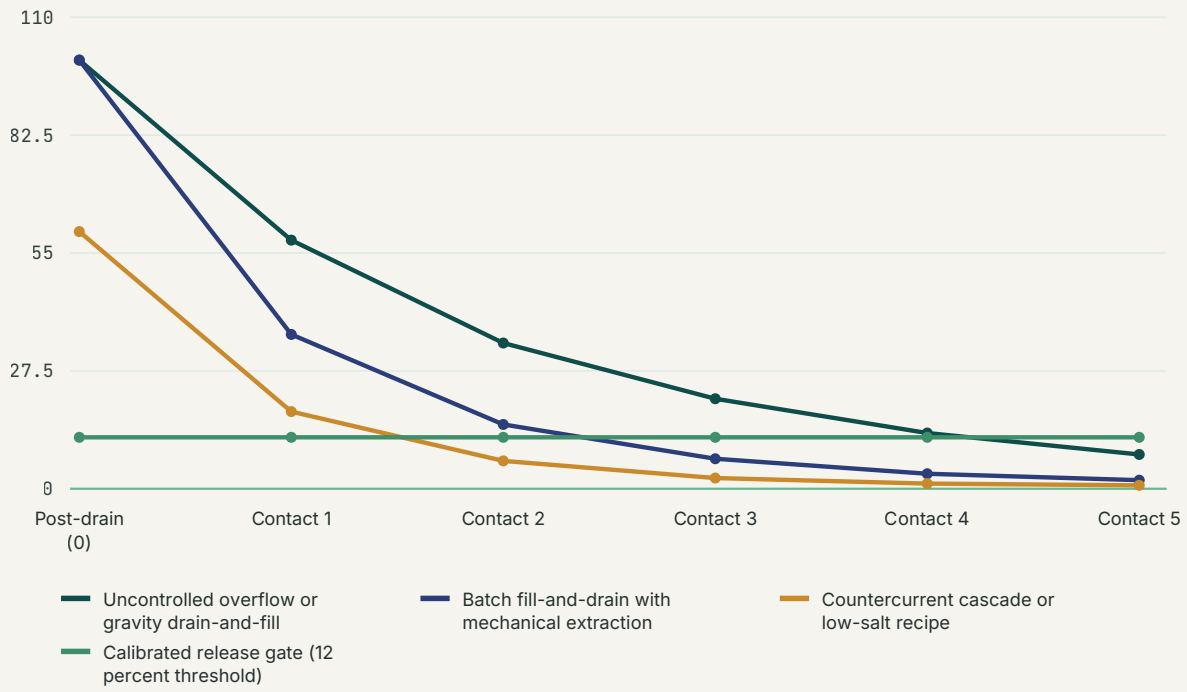
Conductivity and colour can signal the endpoint, with validation

7.12 INLINE SENSORS TRACK ELECTROLYTE DILUTION AND CHROMOPHORE WASHOUT IN REAL TIME

Replacing fixed timers with mass-transfer control requires a physical signal indicating when the wash bath reaches residual specification. [S02] [S0701] [S0702] Because cotton and denim wash-off removes dissociated electrolytes (NaCl, Na2SO4, Na2CO3, NaOH, NaOCl, Na2S2O5) and water-soluble hydrolysed dyes, **electrical conductivity (**EC**)**, **total dissolved solids (**TDS**)**, **pH** and **optical absorbance** are primary endpoint indicators. [S31] [S0701] [S0702] In conventional dark-shade reactive washing (S0702 Table 7), EC fell monotonically from 13,820 uS/cm (dyebath) to 8,540 (drain), 4,120 (60 degrees Celsius wash), 1,760 (first 90 degrees Celsius soaping) and 930 uS/cm (second 90 degrees Celsius soaping) as pH dropped from 11.8 to 7.3, whereas the cationised route (S0702 Table 8) fell from 6,300 to 3,140, 1,120 and 490 uS/cm (TDS 540 mg/L) in one fewer stage. [S0702]

EXHIBIT 30 / RESIDUAL ELECTROLYTE INDEX (%)

An endpoint curve replaces a fixed number of rinse baths



ILLUSTRATIVE [S31] [S0701] [S0702] Illustrative mass-transfer dilution trajectories grounded in the stage-by-stage conductivity and TDS decay profiles reported in S0702 (Tables 7 and 8), S0701 (two-rinse denim dilution) and S31 (post-dyeing wash-off). The flat series at 12 percent represents an illustrative local release gate calibrated to laboratory fastness.

Exhibit 30, p. 118 shows how an endpoint release gate operates across three illustrative dilution trajectories grounded in S0701, S0702 and S31. [S31] [S0701] [S0702] Under a fixed five-contact quota, every batch runs to Contact 5. Under an endpoint gate set at an illustrative 12 percent residual index, gravity drain-and-fill still requires five contacts (8 percent), batch drain-and-fill with mechanical extraction crosses below threshold at Contact 3 (7 percent), and the countercurrent or low-salt route crosses at Contact 2 (6.5 percent), releasing the batch three fills early. [S31] [S0701] [S0702]

7.13 SENSOR READINGS BECOME RELEASE CONTROLS ONLY AFTER LOCAL CALIBRATION AGAINST FASTNESS

An uncalibrated conductivity probe cannot be set to a universal threshold to release every batch because EC responds to mobile inorganic ions (Na+, Cl-, SO4^2-), whereas wash fastness (ISO 105-C06) and rubbing fastness (ISO 105-X12) depend on slower-diffusing hydrolysed dye molecules. [S31] [S36] [S0702] Cold rinsing can flush salt from macro-pores and drop EC rapidly while hydrolysed dye remains trapped inside cellulose microfibrils until hot soaping (75 to 98 degrees Celsius) provides thermal energy for diffusion. [S02] [S31] [S0702] Moreover, makeup water conductivity and hardness vary widely (545 uS/cm at 214 mg/L CaCO3 in tap water vs 1,925 uS/cm at 67.7 mg/L CaCO3 in UF permeate in S0704; hardness shifts shade across 10, 40 and 70 degrees dH in S37), and high chloride (> 3 g/L in denim bleaching, S0701) interferes with chemical tests. [S37] [S0701] [S0704]

METHOD

GFT calibration protocol for turning conductivity, pH and optical sensors into batch release gates. Before any sensor terminates a rinse automatically, the laboratory and utilities team must execute four steps per dye class and shade bracket: [S18] [S31] [S33] [S0701] [S0702] 1. **Baseline subtraction for incoming water:** Log temperature-compensated conductivity (EC_{in}, uS/cm at 25 degrees Celsius), TDS, pH and hardness (mg/L CaCO3 or degrees dH) of feed water and track net differential $\Delta\text{EC} = \text{EC}_{\text{bath}} - \text{EC}_{\text{in}}$. [S37] [S0702] [S0704] 2. **Paired stage sampling after thermal hold:** Across at least 10 batches per shade bracket, sample bath liquor and fabric swatches after the required hot-diffusion hold (60 to 90 degrees Celsius), measuring ΔEC, TDS, pH and UV-Vis absorbance at $\lambda_{\max}$ (S31, S36, S0702). 3. **Fastness and shade verification:** Test matched swatches for ISO 105-C06 wash fastness, ISO 105-X12 dry/wet rubbing fastness, extract pH and dried D65 CIELAB colour difference (dE) (S31, S37, S0702). 4. **Safety-margined threshold and ZDHC audit:** Set the release threshold 15 to 20 percent stricter than the highest net ΔEC and absorbance at which 100 percent of swatches achieve $\geqslant$ 4 (4 to 5 in S31, S0702) fastness, verify composite discharge against ZDHC Wastewater Guidelines (V2.2, S33), and re-calibrate quarterly. [S18] [S31] [S33]

7.14

Rinse heat belongs in the same optimisation

7.15 HOT WASHING AND DRYING DOMINATE THE THERMAL BALANCE OF SEPARATION

Optimising rinsing solely around cubic metres of water while ignoring temperature and post-wash moisture risks trading a minor water saving for a severe steam penalty. [S01] [S16] [S17] In wet-processing energy analyses across China, Japan and Taiwan (S16), preparation, dyeing/printing and finishing demand 50 percent of factory thermal energy, split between hot process baths (40 to 100 degrees Celsius) and convective drying (100 to 180 degrees Celsius). [S16]

Rinsing governs both thermal sinks. [S01] [S16] [S0702] First, reactive dye desorption requires hot washes (60 degrees Celsius) and boiling soapings (90 degrees Celsius in S0702; 98 degrees Celsius for machine boil-outs in S0704); cutting one 90 degrees Celsius boiling bath and lowering soaping to 75 degrees Celsius via cationised dyeing (S0702) saves both water and sensible heat (2.72 MJ/kg to heat 10 L/kg from 25 to 90 degrees Celsius at 4.184 kJ/kg/K before boiler losses, S17). [S01] [S17] [S0702] [S0704] Second, mechanical dewatering after the final rinse sets the evaporative load entering the dryer: evaporating residual water thermally requires 2.26 MJ/kg latent heat (3.0 to 4.5 MJ/kg including dryer exhaust losses in S01, S16, S17), an order of magnitude above mechanical squeezing. [S01] [S16] [S17]

7.16 EFFLUENT HEAT RECOVERY REQUIRES FOULING PROTECTION AND SINK MATCHING

Both IFC (S01) and EU BAT (S02, S38) recommend recovering heat from warm wash effluents (60 to 95 degrees Celsius) to preheat incoming fresh water. [S01] [S02] [S17] [S38] Continuous countercurrent washers provide simultaneous hot discharge and cold intake streams for direct heat exchange, whereas batch drains are intermittent and carry lint, microfibres and pumice grit (TSS up to 1,290 mg/L in stone-

washing, S0701) that foul exchanger plates. [S01] [S17] [S0701] Following the US DOE systems approach (S17), GFT requires three design checks before approving rinse heat recovery: insulated buffer tanks to match batch drain and fill timestamps (S17, S0704), automatic self-cleaning lint screens with differential-pressure monitoring upstream of exchangers (S01, S17, S0701), and paired trials confirming that any temperature reduction does not inflate water volume or degrade fastness (S17, S31, S0702).

7.17

Garment washing requires a per-piece account

7.18 DENIM AND GARMENT LAUNDRIES OPERATE ON PIECES, AESTHETICS AND MULTI-STAGE BATHS

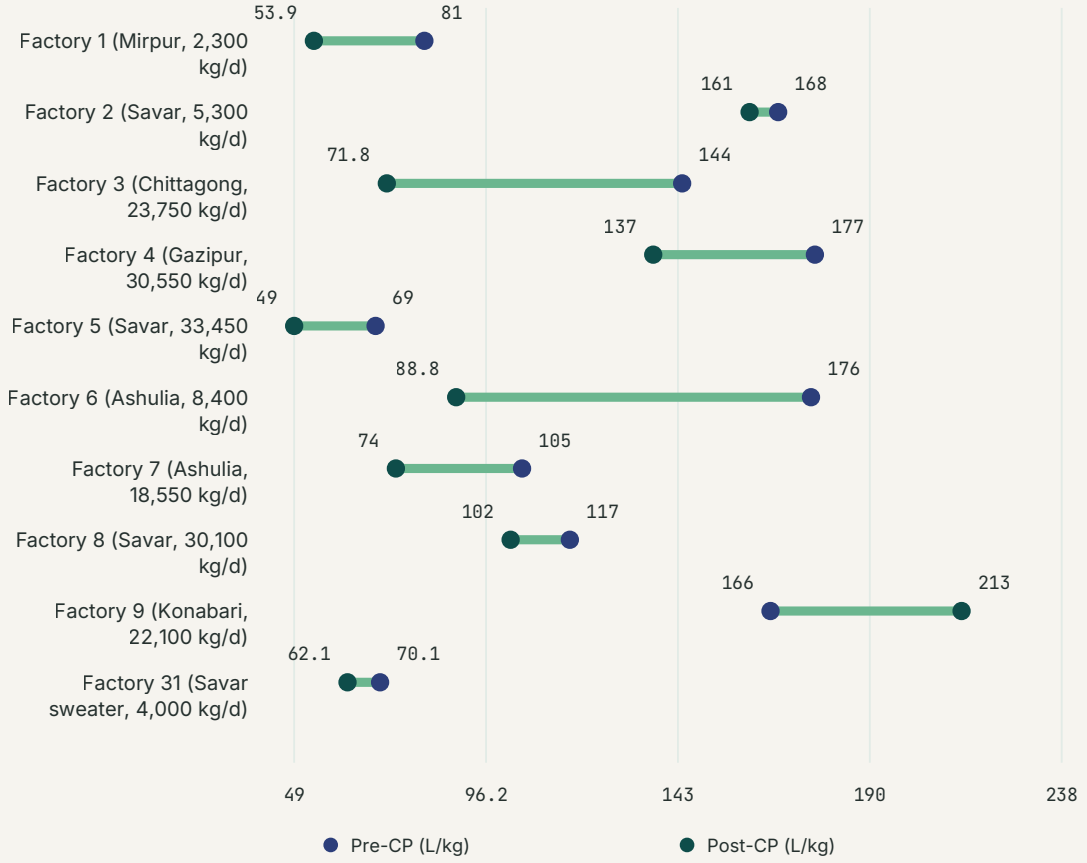
Unlike fabric dyehouses (kg or m), readymade garment (RMG) and denim laundries process discrete articles (pieces) and must track water and energy separately from fabric production (Higg FEM 4.0, S24; 12 MJ/piece and 0.94 kg CO2/piece in S30). [S24] [S30] Conventional stonewashing of denim jeans takes **seven stages and three rinses** (45 to 60 minutes at 55 to 60 degrees Celsius with pumice stones), whereas dry laser fading reduces the route to **six stages and two rinses** (3-minute room-temperature laser exposure), and enzymatic cellulase washing eliminates pumice sludge (S0703). [S0701] [S0703] Synthetic-blend denim washing also sheds microfibres (2,300,000 to 4,900,000 microfibres/kg on 97 percent PET / 3 percent Lycra denim, cut by 27.5 percent on 50 percent PET / 50 percent cotton blends in S0703), requiring laundry drain filtration. [S0703]

7.19 CLEANER-PRODUCTION AND NANOBUBBLE CASES MUST SEPARATE BASELINE, PROJECTION AND VERIFIED RESULT

GFT separates **measured baselines**, **project or vendor projections**, and **verified operating series** in garment-washing ledgers. [S07] [S08] Under UNIDO's MED TEST II project in Tunisia (S07), denim finisher New Amico (processing 2.8 million pairs of jeans annually) installed three E-flow nanobubble machines that transport finishing chemicals in a moist-air nanobubble mist rather than free bath liquor (S07, S0703). While review literature (S0703) notes vendor claims of up to 95 percent water, 90 percent chemical and 40 percent energy reductions in application steps, UNIDO reports the specific project projection for New Amico: reducing water consumption for washing jeans by **13 litres per piece**, or **36,480 m3/year** (plus 189,225 kWh/year and 26.5 tonnes/year of chemicals, worth EUR 254,321/year against a EUR 244,500 investment). [S07] [S0703] GFT logs 13 L/piece explicitly as a **commissioned project projection** (S07), distinct from post-installation metered history.

EXHIBIT 31 / WATER INTENSITY (L/KG)

Cleaner-production cases show reductions while preserving case identity



SOURCED [S08] Transcribed directly from 2030 Water Resources Group / World Bank report S08 Appendix C (pages 41 to 42, 'Water use data in textile factories: Garment Washing Industry' for Factories 1 to 9 and Factory 31 Sweater washing). Note that Factory 9 (Konabari) rose from 166.05 to 213.0 L/kg post-implementation, illustrating why unnormalised period comparisons without recipe and product controls can move backward.

The factory pairs in **Exhibit 31**, p. 121, transcribed from Appendix C of the 2030 Water Resources Group / World Bank Bangladesh report (S08), show why case identity must be preserved. [S08] Across nine garment-washing plants (2,300 to 33,450 kg/day) and one sweater-washing plant (Factory 31, 4,000 kg/day), pre-implementation water use ranged from 69.01 L/kg (Factory 5) to 176.96 L/kg (Factory 4). [S08] Eight garment-washing plants and Factory 31 (70.12 to 62.11 L/kg) reduced intensity after cleaner-production interventions, led by Factory 3 (144.34 to 71.77 L/kg) and Factory 6 (176.0 to 88.81 L/kg), but **Factory 9 in Konabari (22,100 kg/day) rose from 166.05 to 213.0 L/kg**, proving that unnormalised period comparisons without product and recipe controls can move backward. [S08] [S24] [S29]

EXHIBIT 32 /

A rinse trial records quality and resource in the same row

Trial record field	Unit and boundary	Measurement or test method	Literature reference example	Release or stop rule
Substrate and lot identity	Lot ID, fibre, GSM, piece mass (g/piece) and shade depth (% owf)	Weighbridge, piece counter and recipe link	160 GSM cotton knit at 0.13 to 5.78% dye (S0702); washed jeans (S07)	Hold fabric construction, piece weight and shade identical across paired trials
Mechanical extraction carryover	L retained liquor per kg dry textile (or % wet pick-up)	Gravimetric wet-minus-dry swatch weight after nip or centrifuge	Mechanical liquor extraction before and between washes (S01, S02)	Verify nip pressure or hydro-extraction speed before altering water flow
Freshwater and cascade volume	L/kg accepted fabric AND L/piece accepted garment (by stage)	Submetered inlet flow totaliser per wash box or batch fill	41 to 89 L/kg by shade (S0702); 13 L/piece projected reduction (S07)	Record baseline, projection and verified operating series in separate columns
Thermal profile and cycle time	Bath temperature (C), hold time (min), steam or heat (MJ/kg or MJ/piece)	RTD temperature probe, batch timer and steam/heat submeter	60 C warm wash plus 75 to 90 C soaping (S0702); 98 C machine wash (S0704)	Reject cold-rinse substitutions that increase total water or fail fastness
Endpoint bath indicators	Net EC (uS/cm), TDS (mg/L), pH and optical absorbance at lambda_max	Calibrated inline/bench EC-pH meter and UV-Vis spectrophotometer	Final bath EC 490 to 930 uS/cm, TDS 540 to 1,150 mg/L, pH 7.3 (S0702)	Release bath only when calibrated net EC, pH and absorbance pass threshold
Colour and fastness gate	CIELAB dE, ISO 105-C06 wash fastness, ISO 105-X12 dry/wet rubbing	Spectrophotometer (D65) and grey-scale grading (1 to 5 scale)	Wash and rubbing fastness 4 to 5, dE within tolerance (S31, S37, S0702)	Hard stop: zero tolerance for fastness downgrade or reprocessing increase
Effluent and reuse compliance	COD, BOD5, TSS (mg/L), colour (Pt-Co) and ZDHC MRSL parameters	Composite stage sampling per ZDHC Wastewater Guidelines V2.2 (S33)	Rinse 2 COD < 1,000 mg/L, TSS < 400 mg/L, WQI down up to 70% (S0701)	Route to reuse or discharge only when analytical limits are verified

DERIVED [S07] [S31] [S33] [S37] [S0701] [S0702] Derived from laboratory and factory trial variables in S31, S37, S0701 and S0702, UNIDO garment-washing accounting in S07, and ZDHC Wastewater Guidelines V2.2 in S33.

7.20 PAIRED TRIAL RECORDS PREVENT QUALITY REGRESSION AND DENOMINATOR DRIFT

To prevent rinse reductions from shifting burden onto rework or dryer steam, **Exhibit 32**, p. 122 defines GFT's single-row trial record. [S07] [S31] [S33] [S37] [S0701] [S0702] Every garment-washing or fabric-rinsing trial logs both L/kg and L/piece (with piece

weight in g/piece) alongside thermal input (MJ/kg, MJ/piece), final bath net EC and TDS, ISO 105-C06 and ISO 105-X12 fastness grades, right-first-time (RFT) pass rate and ZDHC effluent compliance. [S07] [S30] [S31] [S33] [S37] [S0702]

GFT NOTE

Practical implementation of mass-transfer rinsing in GFT's Cameroon programme and tool architecture. As Cameroon works to expand local cotton processing from roughly 95 percent raw export and 5 percent local transformation (R06) toward the 50 percent benchmark by 2030 (R07), GFT's core garment-finishing operations and partnered wet mills apply three rules: [R06] [R07] [S24] 1. **Procure countercurrent extraction and segregated drains:** Require inter-stage mechanical dewatering, speed-interlocked valves (S01, S02, S38) and split drain headers for high-load main baths versus reusable Rinse 2 streams (S0701). 2. **Connect endpoint signals to the batch spine:** Log inline EC, pH, temperature and water flow in the batch record (wp18, R01; edge-architecture tool, R02, R03) and cascade L/kg, L/piece, MJ/kg and MJ/piece into shift reviews (wp02, R01; kpi-cascade and footprint tools, R02, R03). 3. **Gate rinse savings on fastness release:** Approve no water reduction unless paired swatches pass the colour and fastness rules shared with wp11 (R01), keeping water, heat, ZDHC discharge (S33) and RFT quality (S37) in one balance. [R01] [R02] [R03] [S33] [S37]

A rinse ends when the fibre and the boundary layer reach chemical specification, not when a timer expires or an overflow tank fills.

CHAPTER SOURCE NOTES

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S02 European Commission Joint Research Centre. 2023.

S0702 Elsevier, Heliyon. 2023-09-04.

S31 Springer Nature, Scientific Reports. 2022-12-26.

S36 Elsevier, Dyes and Pigments. 2024.

S0701 Springer Nature, Scientific Reports. 2026-05-02.

S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.

S38 European Commission. 2022-12-09.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

S04 PLOS Sustainability and Transformation. 2023-07-31.

S05 MDPI, Textiles. 2022-09-28.

S37 Emerald Publishing Limited. 2019.

S33 ZDHC Foundation. 2024.

S0704 MDPI, Membranes. 2022-04-21.

S24 Sustainable Apparel Coalition. 2022.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

S18 International Organization for Standardization. 2018.

S16 MDPI, Energies. 2022-11-25.

S30 Springer Nature, Energy Efficiency. 2024-12-03.

S0703 American Chemical Society, ACS Omega. 2023-01-13.

S07 United Nations Industrial Development Organization. 2018-03-22.

S08 2030 Water Resources Group, World Bank. 2015.

R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.

R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.

R01 Business in Cameroon. Publication date unrecorded; inherited source-text check.

R02 Fibre2Fashion; Business in Cameroon. Publication date unrecorded; inherited source-text check.

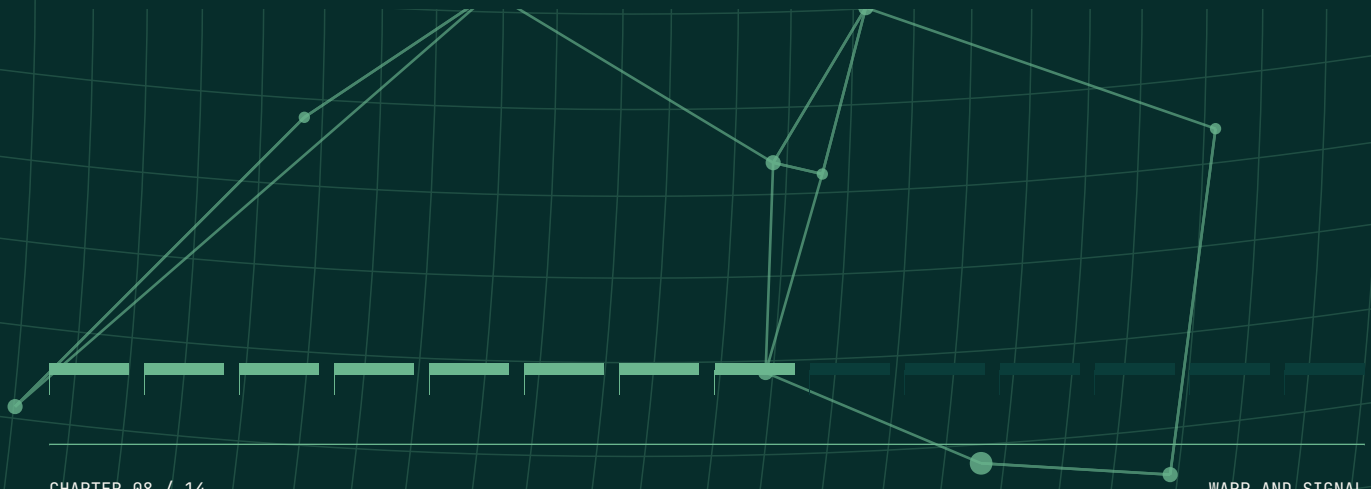
R03 SODECOTON. Publication date unrecorded; inherited source-text check.

08

PART II: THE PROCESS SETS THE FLOOR / DRYING AND FINISHING

Mechanical water removal should precede thermal drying

Removing liquid before evaporation can reduce the drying duty, provided that fabric quality, finish chemistry and accepted output remain inside the test.



CHAPTER 08
DECISION TEST

Removing liquid before evaporation can reduce the drying duty, provided that fabric quality, finish chemistry and accepted output remain inside the test.

Mechanical water removal should be tested before additional thermal drying capacity is specified. The decision is conditional: remove as much liquid as the fabric and finish permit, then supply the heat needed to reach the approved moisture, dimensional and cure endpoints. IFC explicitly identifies mechanical dewatering before the stenter as an energy-reduction technique. [S01] GFT's proposed operating method is to follow the water through extraction, subsequent liquor application, drying and quality release, and to compare the complete route against accepted dry fabric mass. A lower entry-moisture reading establishes a smaller potential evaporation duty. It does not, by itself, establish a lower fuel bill or an acceptable finished fabric.

This chapter proposes a measurement and trial specification, rather than reporting an installed GFT drying system. Its recommendations distinguish liquid removed, water evaporated, delivered heat, electricity and released fabric. Those quantities should remain separately visible even when management asks for a combined energy or cost indicator. The preceding washing decision supplies the fabric condition at entry. The following reuse decision determines the destination of extracted liquid. Here the central question is narrower: which water must enter the thermal stage, and what evidence permits changing that amount?

8.1

Drying and curing are priority thermal loads

IFC describes heat consumption as particularly significant in drying, curing and wet treatments. [S01] The practical implication is to draw the audit boundary around the textile route, rather than treating boiler performance as the complete answer. GFT recommends listing every heated passage between washing and final release, its purpose, the fabric condition at entry and the utility serving it. A boiler improvement and a reduction in evaporation are different interventions. Keeping them separate allows an engineer to determine whether the process actually needs less heat or the supply system delivers the same heat with fewer losses.

The electrification study by Hasanbeigi and Zuberi places preparation, dyeing, printing and finishing at the centre of thermal demand in its typical composite-plant description. [S16] That description helps prioritise investigation; it is not a Cameroon design coefficient. GFT recommends treating published process allocations as prompts for the first walk-through. The site's own meters, product routes and operating schedule should decide the final ranking. A garment-only operation, a fabric finisher and an integrated wet-processing plant should not inherit the same drying account simply because each belongs to textiles.

For the proposed audit, the engineer should distinguish useful evaporation, required heating of the textile, finish reaction or fixation, circulating-air heating and unproductive losses. Some loads may change when entry moisture changes; others may persist. A fixed-temperature chamber that continues to run empty does not necessarily reduce its consumption when a wetter batch is replaced by a drier one. GFT therefore recommends recording operating state beside energy: heating, loaded production, gap between batches, waiting, cleaning and shutdown. The resulting record should permit the reviewer to isolate a physical improvement from a change in operating hours.

The heat balance should also state its energy boundary. A steam meter at the machine measures something different from boiler fuel purchased at the site. Where heat is calculated from steam, the proposed method should retain pressure, steam condition, condensate assumptions and the calculation version. Where fuel is metered directly, retain its calorific-value convention. Electricity should include extraction drives and the relevant drying auxiliaries. GFT recommends rejecting any comparison that moves upstream losses into one route but leaves them outside the other, even when both reported quantities use the same energy unit.

DOE's process-heating sourcebook recommends examining interacting components through material and energy flows. [S17] GFT applies that principle through a route sketch completed before equipment quotations are compared. Mark where liquid leaves, where fresh liquor returns and where heat enters. State which meters already exist and which readings would be estimates. Record the intended improvement in operational language: lower dryer entry water at unchanged finish performance, for example. This makes a request for a larger dryer contestable. The capacity shortfall might instead be water carried unnecessarily into the existing machine, avoidable waiting, or a route that repeats a function.

The audit's first deliverable should therefore be a ranked list of unanswered questions. Does the measured entry moisture match the recipe assumption? Is the bottleneck evaporation, required curing time or fabric handling? Does the energy meter include the same production window as the release record? GFT recommends answering these before selecting a new heat source. The distinction prevents an efficient replacement machine from being sized around an avoidable duty.

8.2

The water-removal sequence determines avoidable evaporation

The European Commission's textile BAT reference describes centrifugation, vacuum extraction and squeezing rollers as mechanical dewatering options. [S02] GFT recommends screening them against the fabric envelope before comparing utilities. The trial brief should state construction, fibre blend, surface finish, width, wet strength and acceptable handling. It should also state whether the liquid is wash water or a deliberately applied finishing bath. Removing unwanted rinse water and changing chemical pickup are different decisions. The latter requires recipe approval as well as a moisture measurement, because the retained liquid can carry the material that creates the finish.

Under GFT's proposed protocol, residual moisture is recorded on a dry-mass basis. Let D be the reference dry textile mass and W the associated water mass. The dry-basis ratio r equals W divided by D. A wet-basis fraction x instead equals W divided by the combined mass of water and dry textile. The conversion is r equals x divided by the quantity one minus x. Use the words “dry basis” or “wet basis” in every field label. The protocol should never rely on a percentage sign alone to convey which denominator was used.

An illustrative conversion shows the consequence. A dry-basis ratio of 0.80 kg water per kg dry textile corresponds to a wet-basis fraction of 0.80 divided by 1.80, or about 44.44 percent. A wet-basis fraction of 80 percent instead corresponds to 4.00 kg water per kg dry textile. These are constructed calculations, not measurements or target values. Confusing the labels would produce a materially different dryer duty even though the displayed numeral looked familiar.

GFT recommends establishing a reference sampling procedure with the site's textile laboratory. It should specify sampling positions across the width and along the batch, immediate handling to limit evaporation, weighing equipment and the method used to establish reference dry mass. Where finishes or volatile components are present, the laboratory should establish whether apparent mass loss represents water alone. The production sensor should be checked against that reference for the actual product family. Record calibration limits, uncertainty and exclusions. An instrument reading outside its validated product envelope should remain provisional.

The sequence in **Exhibit 33**, p. 128 is an illustrative measurement design informed by the source descriptions, rather than an implemented control system. It deliberately includes any liquor addition after extraction. Omitting that point would allow a convincing extractor result to disappear before the dryer inlet. [S01] [S17]

EXHIBIT 33 / PROPOSED MEASUREMENT SEQUENCE

The dryer inlet must be measured after any liquor addition



ILLUSTRATIVE [S01] [S17] Illustrative GFT meter-point design informed by mechanical dewatering and systems analysis. At each textile point record dry-mass basis and moisture. Measure extraction electricity and dryer heat separately. No installed system is asserted.

For the proposed mass balance, water requiring removal equals D multiplied by the difference between entry and release dry-basis ratios, plus water added within the boundary. Account separately for any liquid drain within that same boundary. This is an inventory equation, not a drying-rate model. It does not establish the time needed, the uniformity achieved or whether the fabric tolerates the selected extraction pres-

sure. Reconcile the textile balance against collected liquid and available process measurements. A persistent unexplained discrepancy should suspend the saving claim while sampling and stream coverage are checked.

> **UNCERTAINTY BELONGS BESIDE THE MOISTURE REDUCTION**
>
> For an illustrative uncertainty check, retain the worked example's dry mass of 1,000 kg but assume each entry-moisture ratio has an absolute uncertainty of 0.02 kg/kg dry. The lowest compatible baseline ratio is then 0.78 and the highest compatible candidate ratio is 0.62. Their difference supports only 160 kg of avoided evaporation. The opposite combination, 0.82 minus 0.58, gives 240 kg. These are conservative arithmetic bounds from assumed measurement limits, not a statistical confidence interval. Common calibration errors and sampling variation should be investigated separately rather than automatically treated as independent.
>
> GFT recommends using the lower defensible benefit for screening until better measurements narrow the interval. Include uncertainty in reference dry mass and utility measurements where material. If the measured reduction is comparable to the unresolved measurement error, describe the trial as inconclusive. Do not compensate by averaging more readings from the same uncalibrated instrument. Improve the reference method, sampling coverage or meter selection before extending the operating claim.

GFT also recommends inspecting where extracted liquid goes. A drain flow demonstrates liquid separation, not freshwater conservation. If extraction merely moves water from dryer exhaust to wastewater, report that redistribution directly. Credit a reduction in freshwater intake only when a separate intake or reuse balance supports it. This keeps the chapter's energy opportunity connected to the paper's wider water account without giving the same litre incompatible meanings.

8.3

Dryer control needs a moisture endpoint

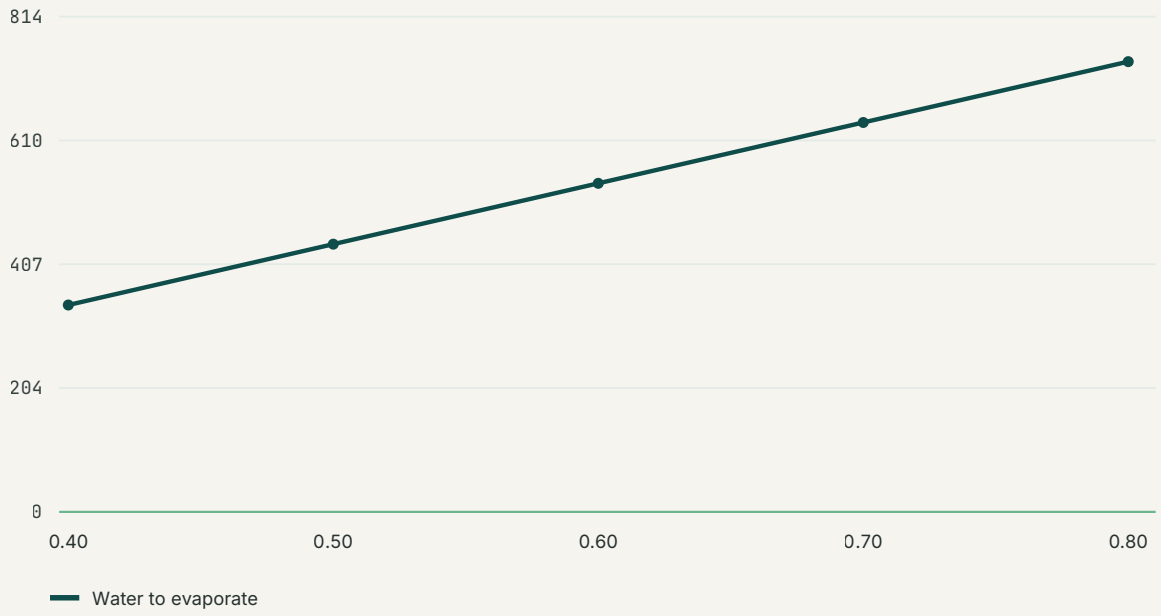
DOE defines drying as removal of free water through heating. [S17] GFT's control proposal starts with the required exit condition, not the maximum dryness the equipment can achieve. The product specification should state the release-moisture method, the conditioning interval before inspection and the required consistency across the fabric. The process engineer and quality owner should agree these rules before the trial. Otherwise a candidate route could appear efficient by releasing wetter fabric, or appear productive by leaving a downstream operation to complete the drying duty.

The BAT reference includes avoiding overdrying and monitoring residual moisture among stenter and dryer techniques. [S02] GFT recommends separate records for the process endpoint and the commercial release test. A reading taken immediately at the hot outlet answers a different question from a sample conditioned for quality assessment. Keep their locations and timing explicit. Use the outlet instrument to guide the process only within its validated range, and retain the release test as the acceptance authority. A moisture sensor should not silently replace a required functional or dimensional test.

The illustrative relation in **Exhibit 34**, p. 130 isolates the inventory effect. Its equally spaced entry-moisture assumptions share a fixed dry mass and release condition. The straight line comes from subtraction; it is not an experimentally established dryer performance curve.

EXHIBIT 34 / KG WATER PER ILLUSTRATIVE BATCH

Less inlet water reduces the inventory requiring evaporation



ILLUSTRATIVE Illustrative arithmetic: D = 1000 kg dry textile; exit r = 0.06 kg/kg dry. Entry labels are kg water/kg dry. Evaporation = D times (entry r minus 0.06), with no internal addition or liquid drain. No heat or drying-time coefficient is inferred.

To convert this inventory into an energy decision, GFT recommends estimating a local marginal response from matched trials. Record delivered heat, entry water, exit water, speed, operating hours and relevant ambient conditions. Preserve the observations before fitting a relationship. A fixed loss plus a moisture-dependent term may be a useful candidate model, but residuals and operating-state changes should decide whether it is adequate. Do not force a straight heat-consumption line merely because the inventory equation is linear. Different control states or product families may require separate models.

WORKED EXAMPLE: THE EVAPORATION REDUCTION MUST SURVIVE ELECTRICITY AND YIELD

This illustrative example assumes 1,000 kg of reference dry textile, all accepted in both routes. Entry moisture falls from 0.80 to 0.60 kg water per kg dry textile; release remains 0.06. There are no internal liquid additions or drains. Baseline evaporation is 1,000 multiplied by (0.80 minus 0.06), or 740 kg. Candidate evaporation is 540 kg. The mechanically avoided evaporation is therefore 200 kg.

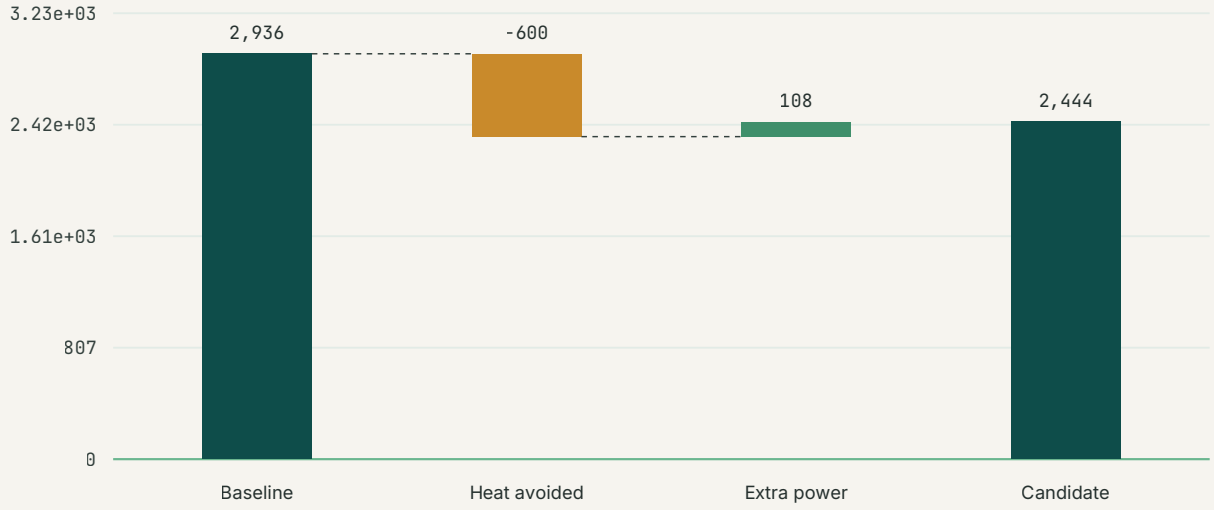
For this illustrative model, assume a marginal delivered-heat requirement of 3 MJ per kg evaporated water and a fixed batch heat requirement of 500 MJ. These are chosen sensitivity inputs, not published dryer factors. Baseline heat is 500 plus 3 multiplied by 740, or 2,720 MJ. Candidate heat is 2,120 MJ. Assume combined extractor and dryer-auxiliary electricity rises from 60 to 90 kWh per batch. Using 3.6 MJ per kWh as a unit conversion, total final-energy input falls from 2,936 to 2,444 MJ. The net reduction is 492 MJ per batch, about 16.76 percent, rather than the 600 MJ thermal reduction alone.

On the same illustrative accepted-output basis, delivered heat falls from 2.720 to 2.120 MJ/kg, electricity rises from 0.060 to 0.090 kWh/kg, and combined final energy falls from 2.936 to 2.444 MJ/kg. This addition is an energy inventory, not a carbon or cost calculation. If candidate accepted output instead fell to an assumed 800 kg, its unchanged batch energy would become 3.055 MJ/kg accepted, exceeding the original ratio. Any later reprocessing would add further energy. The example therefore permits no saving claim without the quality denominator.

The waterfall in **Exhibit 35**, p. 132 reconciles that illustrative calculation. It does not value electricity and heat equally in money or emissions. Those comparisons need separate, dated prices and applicable emission factors. A proposed machine investment should carry both physical results and the assumptions used to translate them into a commercial decision.

EXHIBIT 35 / MJ FINAL ENERGY PER ILLUSTRATIVE BATCH

Added electricity reduces the illustrative thermal benefit



ILLUSTRATIVE Illustrative inputs: 1000 kg dry accepted textile; r entry 0.80 to 0.60; r exit 0.06; marginal heat 3 MJ/kg water; fixed heat 500 MJ; electricity 60 to 90 kWh; conversion 3.6 MJ/kWh. Baseline 2720 + 216 = 2936; candidate 2120 + 324 = 2444. No primary-energy, emissions or cost equivalence is asserted.

A trial report should also distinguish a calculated opportunity from an observed response. In the illustrative worked case, the thermal reduction follows directly from the assumed marginal coefficient. A real machine might hold the same firing rate, raise production speed, or run for less time after dewatering improves. GFT recommends recording which response actually occurred. Report additional capacity separately if the line produces more accepted fabric without reducing total heat. That can still be operationally valuable, but it is a different result from lower absolute energy consumption.

For a batch comparison, the proposed metering window should begin before the relevant warm-up and end after the associated production and shutdown activities. If a shared machine makes direct batch separation impractical, define a matched campaign window instead. Retain opening and closing energy readings and the production events between them. Flag any window containing an unrelated maintenance intervention or a changed product mix. A good-looking consumption difference should remain provisional when its boundaries cannot be reconciled.

The example should be repeated with measured inputs before approval. GFT recommends testing a conservative combination of lower avoided evaporation, higher extractor demand and unchanged fixed losses. If the project only succeeds under the most favourable assumptions, obtain better measurements or narrow the proposed product envelope. A trial can establish that an intervention is unsuitable for part of the product range without invalidating its use elsewhere.

8.4

Finishing routes determine how often drying is repeated

Hasanbeigi and Zuberi distinguish fabric drying, stenter heat setting and pad-dry-cure finishing in their process analysis. [S16] GFT recommends translating those functions into a route register. Every heated passage should identify what physical or chemical requirement it satisfies, which specification controls release and what would fail if the passage were removed. A machine name is insufficient. A stenter can appear repeatedly in the register while performing different functions. Eliminating a repeated machine visit is defensible only when the product still receives every necessary treatment.

The BAT reference discusses scheduling and repeated stenter treatment within its energy review. [S02] GFT proposes reviewing route redundancy with production and quality together. Start with the approved route, then mark intermediate storage, wetting, inspection and any finish application between heated passages. Determine whether an intermediate dry state is technically necessary or simply convenient for the current schedule. A proposed combination of operations should be trialled as a new route, with its own release evidence. It should not be adopted as an undocumented shortcut after the drying meter has shown a promising reduction.

The route comparison in **Exhibit 36**, p. 133 records qualitative process distinctions from the electrification study. The acceptance checks are GFT's proposed questions, not source-reported performance guarantees. A table is preferable to plotting unsupported numerical rankings for fabric compatibility or technology maturity. [S16]

EXHIBIT 36 / PROCESS DESCRIPTIONS AND PROPOSED CHECKS

A drying route must preserve the function of each heated pass

Route	Process feature	GFT trial check
Cylinder	Contact drying	Surface and hand
Hot air	Convective drying	Moisture uniformity
Infrared	Radiant heating	Fabric heat profile
Stenter	Heat setting	Width and shrinkage
Pad-dry-cure	Apply, dry, fix	Add-on and cure

DERIVED [S16] Derived qualitative comparison from S16 sections on drying, stenter heat setting and pad-dry-cure. The final column is GFT's proposed trial check. No efficiency ranking or universal temperature is assigned.

For a proposed route reduction, GFT recommends keeping the chemical account beside the moisture account. If squeezing follows finish application, measure the pickup and verify that the finish remains within its approved range. If a route changes from dry-on-dry to another application sequence, confirm compatibility with the chemical supplier and textile laboratory. A fall in water carried into the dryer can be

undesirable if it accompanies insufficient chemical add-on. The test should ask whether the released fabric performs its intended function, not simply whether less liquid remained at the nip exit.

Route comparisons should also retain indirect consequences. GFT recommends recording handling time, batching delays, crease repairs, inspection holds and cleaning between finishes. A combined route may remove a heating cycle yet create a scheduling constraint elsewhere. Conversely, better sequencing might remove an intermediate drying requirement without a large equipment purchase. Both possibilities should enter the same trial register. Keep operating observations separate from management estimates of future throughput, particularly where the trial runs under unusually favourable staffing or batch preparation.

GFT recommends retaining a physical sample from each candidate route under the agreed sample-control procedure. Record the release tests that matter to the product, such as dimensional change, hand, appearance and functional-finish performance. Where a requirement is assessed after washing or another conditioning step, complete that assessment before claiming route equivalence. The quality owner should set the applicable criteria before energy results are compared, so that a favourable resource result cannot quietly change the acceptance threshold. Keep the original and revised route instructions with the test record.

The proposed acceptance decision should have a limited scope. Approve the tested fabric and finish family, machine configuration and operating envelope. Do not extend a successful plain-fabric result to a raised-surface or sensitive-finish product without evidence. The electrification study specifically notes surface constraints for cylinder drying, illustrating why energy selection cannot be separated from textile function. [S16] Record exclusions as part of the approval, so planners cannot later interpret a general energy target as permission to substitute an unqualified route.

8.5

Stenter control joins moisture, temperature and fabric dimensions

GFT recommends treating a stenter trial as a coordinated control experiment. Entry moisture, fabric speed, air conditions, product temperature, width control and finish requirements should be recorded against the same fabric identity. A proposed speed increase must preserve the required process exposure. A proposed temperature reduction must preserve the finish result. The fabric's release authority should be able to trace a failed test back to the actual machine settings, rather than a recipe version that the operator intended to use.

The BAT reference identifies inlet and exhaust air conditions, residual fabric moisture and fabric temperature as monitoring variables. [S02] GFT recommends keeping the exhaust observation separate from the fabric endpoint. Exhaust humidity describes the air stream; it does not directly certify moisture uniformity through the textile. Equally, an acceptable exit-moisture sample does not prove that exhaust flow is economical. The trial should examine both. Any exhaust change should remain within the engineered ventilation, combustion and emission-control limits for that equipment and finish, rather than being made solely to improve an energy ratio.

GFT's proposed control record should preserve actual values as well as setpoints. Record sensor identity, time alignment and the machine state during each observation. A temperature setpoint does not establish the fabric temperature reached, and a nominal line speed does not describe pauses or threading. Where measurements are sparse, mark the gap instead of interpolating through an unobserved stoppage. A diagnostic dashboard should retain those distinctions so that a smooth trend line cannot hide a broken sensor or a recipe adjustment made during the trial.

For trial sequencing, change the extraction setting first within the approved equipment envelope while holding the downstream recipe stable. Once the moisture effect is characterised, investigate the permitted downstream response. GFT recommends this separation to make the causal interpretation inspectable. Changing nip setting, line speed, temperature and exhaust together might deliver a good product, but it would leave the engineer unable to identify which change mattered. A later combined trial can test the proposed operating package after the individual effects and interactions have been understood.

Commissioning should include a proposed time-alignment test. Track a clearly identified fabric segment from entry sampling through the relevant sensors to the release sample, using the actual transit conditions. Confirm that the data system associates each observation with the correct segment when speed changes or the machine stops. A fixed time offset can be checked during a steady trial, but its validity during interruptions requires separate attention. The trial record should identify periods where the association is uncertain instead of assigning those observations to whichever batch happens to be open in the software.

The statistical record should retain dispersion, not just a batch average. GFT recommends comparing edge and centre moisture, recurring wet bands and differences between the beginning and end of a batch. Define the sampling plan before reviewing the result. If a candidate produces a lower average while leaving a wetter tail, the process may still require slower drying or another pass. Approval should depend on the relevant product tolerance and the uncertainty of the measurement, not an arbitrary improvement in the mean.

> **GFT NOTE**
>
> Issue a joint trial sheet owned by production, utilities and quality. Require a validated moisture basis, matched fabric and finish, complete energy coverage, documented release tests and a route-specific stopping rule. Return to the approved settings when fabric quality, ventilation limits or measurement validity fails. Keep failed trials in the resource account. Approve a setting only for its tested product envelope, and monitor it after ordinary scheduling resumes.

GFT recommends linking the approved settings to the batch genealogy and maintenance record. A damaged roller, altered sensor calibration or changed finish formulation should trigger a defined review of the operating envelope. Preserve the earlier trial as historical evidence, rather than overwriting its inputs with the new recipe. This converts a successful experiment into a controllable production instruction while retaining the evidence needed to diagnose later drift.

8.6

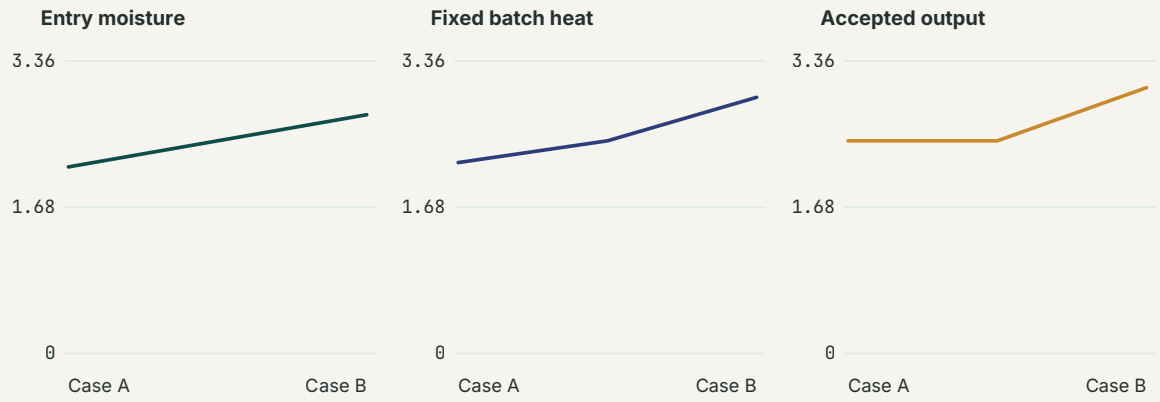
Scheduling and utilisation protect the efficiency gain

The Latvian textile case analysed by Čerdancova and colleagues relates specific energy indicators to production and identifies seasonal behaviour. [S29] It supports examining operating context alongside intensity, without supplying a transferable factory coefficient. GFT recommends reviewing loaded time, idle heating, warm-up, product mix and accepted output together. A dryer that processes less fabric can show a worse per-kilogram ratio even when its extraction system performs identically. Conversely, a busier month can improve the ratio without any technical intervention. Neither pattern should be described as a verified equipment saving without further analysis.

The illustrative panels in **Exhibit 37**, p. 136 show separate sensitivities on a common scale. They are calculated from the worked example, changing a single assumed variable at a time. The labels describe sensitivity cases, not calendar observations. The shared unit permits comparison of the consequences without implying equal likelihood.

EXHIBIT 37 / MJ FINAL ENERGY PER KG ACCEPTED, ILLUSTRATIVE

Moisture, fixed heat and yield can each change the verdict



ILLUSTRATIVE Illustrative reference: D=1000 kg; entry r=0.60; exit r=0.06; heat=500+3 times evaporated kg; electricity=90 kWh. Left, reference, right: entry r 0.50/0.60/0.70; fixed heat 250/500/1000 MJ; accepted dry output 1000/1000/800 kg. Other inputs fixed. Final energy includes electricity times 3.6. Values rounded to 3 decimals. Panels are independent sensitivities, not additive effects.

For the proposed scheduling review, GFT recommends comparing matched production windows as well as matched batches. Allocate warm-up and idle consumption explicitly, using a documented rule that reconciles to the utility total. Do not delete an idle period because it lacks a batch identifier. If a dewatering change increases upstream waiting or creates smaller dryer campaigns, those effects belong to the operating result. The campaign comparison should include the transition back to normal production, since a trial conducted with uninterrupted feed may not represent the planned order book.

ISO's public description of its energy-management framework includes performance indicators and baselines. [S18] GFT recommends assigning an owner to each dryer indicator and a decision to each exception. Production should explain stops and loading, utilities should investigate unexplained consumption, quality should control release and engineering should maintain the comparison model. The review should ask whether performance moved within the qualified envelope before changing targets. A dashboard needs a defined route from signal to investigation; displaying additional decimal places is not a substitute for that responsibility.

The handover should connect to the programme's proposed performance and cost families. Keep accepted output, first-pass release, availability and energy in the same review, while preserving their different meanings. A dryer can be available without receiving fabric, and a batch can leave the machine without passing release. GFT recommends treating these as separate events in the record. Link resource claims to the release event and include subsequent correction when it becomes known. This prevents a rapid first passage from receiving an efficiency credit that later rework reverses.

Annualisation should follow the same discipline. GFT recommends separating qualified product volume from the factory's total planned output, and separating realistic operating hours from equipment availability. Apply the measured result only to the portion that can use the approved route. Present alternative utilisation assumptions explicitly when the order book remains uncertain. Do not multiply a short uninterrupted trial's hourly benefit across every available hour. Include the proposed cleaning, maintenance and calibration requirements in the operating plan, and state who will check that the qualified moisture reduction persists after those activities.

A capital proposal should finish with the tested envelope, unresolved uncertainties, operating instructions and a verification plan for routine production. Any financial appraisal should show its prices and boundary separately from the physical trial. This chapter provides an engineering decision framework, not investment, legal or tax advice. The defensible approval is specific: the proposed extraction and drying sequence meets its product requirements and reduces measured resource input under the tested conditions. Further extension requires further evidence, rather than a broader interpretation of the original result.

Remove the water you do not need to heat, then prove the fabric still does its job.

CHAPTER SOURCE NOTES

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S16 MDPI, Energies. 2022-11-25.

S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.

S02 European Commission Joint Research Centre. 2023.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

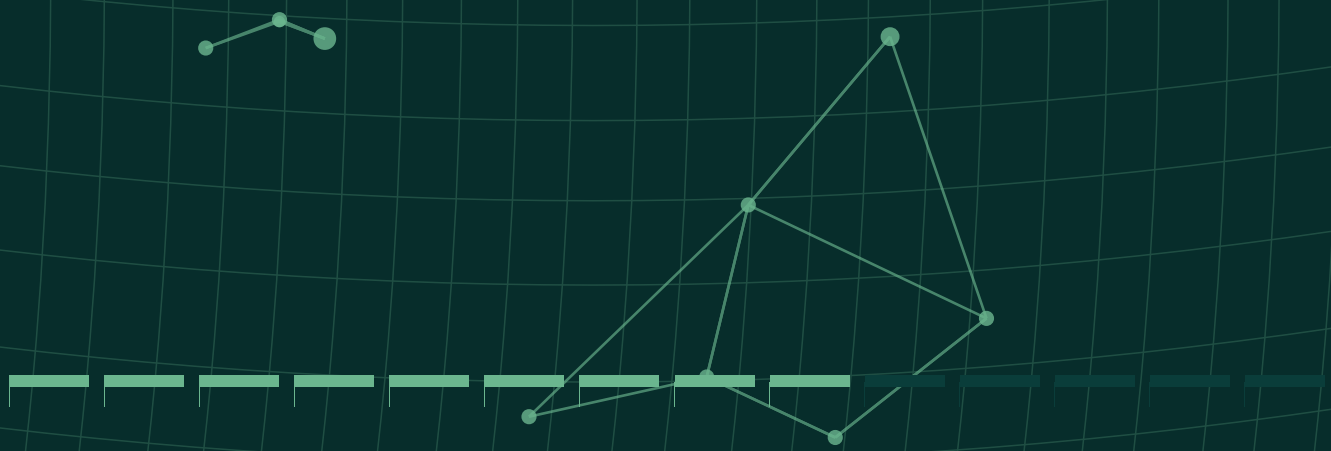
S18 International Organization for Standardization. 2018.

09

PART II: THE PROCESS SETS THE FLOOR / CUT, MAKE, TRIM AND FINISH

Garment making measures electricity, rework and wet finishing together

A garment plant may avoid a dyehouse on site, but it still needs a per-piece account for machines, utilities, washing and every unit that fails first time.



CHAPTER 09
DECISION TEST

A garment plant may avoid a dyehouse on site, but it still needs a per-piece account for machines, utilities, washing and every unit that fails first time.

A garment factory controls its resource intensity only when electricity, steam, compressed air and wet-finishing water are metered against accepted pieces rather than gross bundle counts. [S24] [S30] Because textile wet processing accounts for approximately 60 to 90 percent of total water used in textile manufacturing, audits often treat cut-make-trim plants as minor footnotes. [S03] That assumption fails on the factory floor for three reasons. First, garment assembly and pressing require continuous electrical power, steam and compressed air whose cost share in developing-country plants often exceeds the 5 to 10 percent of production cost reported in developed economies. [S30] [S0902] Second, garment lines that include denim or piece washing reintroduce dyehouse-scale water, chemical and drying loads inside the apparel boundary. [S07] Third, sewing defects, stain removal, re-pressing and rejected garments consume machine time, steam and baseload utilities without adding a saleable unit to the denominator. [S37] In GFT's Cameroon textile programme, prepared 31 January 2024 with source-refresh notes retained in 2026, the core concept centres on cut, make, trim and finishing linked to partnered upstream mills. [R06] [R07] For that model to substantiate any efficiency claim, the garment floor must maintain its own batch and line ledger from the first shift, separating owned assembly utilities from wet finishing and penalising rework inside the per-piece score. [S18] [S24]

9.1

A gate-to-gate garment baseline is measurable

Establishing a garment resource ledger begins by defining a gate-to-gate boundary starting at fabric-roll receipt in the cutting room and ending when inspected, pressed and packed garments pass final quality release. [S24] [S30] Within this envelope, the primary denominator is the accepted garment piece, supplemented by accepted garment mass in kilograms when product mix spans light knitwear and heavy woven trousers. [S29] [S30] Treating the garment factory as a distinct accounting unit aligns with the Higg Facility Environmental Module (FEM) 4.0 technical framework, which requires a facility manufacturing both finished products and fabric on the same site to track and report energy and water consumption separately. [S24] Separate tracking prevents a low-water sewing hall from diluting the apparent intensity of an adjacent dyehouse, and prevents upstream fabric losses from obscuring electricity or steam waste inside the garment plant. [S01] [S24]

9.2 PER-PIECE ENERGY ACCOUNTING REQUIRES EXPLICIT GATE-TO-GATE BOUNDARIES

Empirical literature confirms that gate-to-gate garment energy intensity can be quantified per piece when all fuel and electricity carriers entering the apparel boundary are converted to a common thermal unit. [S29] [S30] An investigation of readymade garment (T-shirt) manufacturing in Bangladesh published in December 2024 evaluated gate-to-gate production stages and documented daily factory consumption of 15,105 cubic metres of natural gas, 49.93 kilograms of oil and 36,265 kilowatt hours of electricity. [S30] Across the studied output, those energy carriers yielded a specific energy consumption of 12 megajoules per piece (3.33 kilowatt hours of primary and secondary energy per garment) and daily carbon dioxide emissions of 56.65 tonnes. [S30] At the unit level, the study recorded specific emis-

sions of 0.94 kilograms of carbon dioxide, 1.69 grams of carbon monoxide, 3.53 grams of methane, 4.1 grams of nitrogen oxides and 0.89 grams of sulphur oxides per piece. [S30]

The lesson from **Exhibit 38**, p. 140 is methodological rather than numerical. [S30] A figure of 12 megajoules per T-shirt proves that an apparel plant can reconcile natural gas for boilers, oil for standby generators and grid electricity for sewing lines into one unit denominator. [S29] [S30] However, importing 12 megajoules as a design coefficient or forecast for a Cameroonian factory would violate data integrity. [S23] [S30] Textile Exchange guidance stresses that life-cycle metrics should be used only when underlying assumptions, boundaries and operating contexts match the decision. [S23] The Bangladesh case reflects a specific factory scale, fuel mix, boiler efficiency and knit T-shirt construction observed during its study window. [S30]

EXHIBIT 38 / REPORTED CASE METRICS (BANGLADESH T-SHIRT PLANT, 2024)

A garment case demonstrates per-piece energy without creating a universal factor

12 MJ/piece

Specific energy per garment

Gate-to-gate T-shirt energy across gas, oil and electricity

36,265 kWh/day

Daily electricity intake

Metered electrical load in the studied Bangladesh facility

15,105 m3/day

Daily natural gas intake

Thermal fuel demand dominated by steam generation

0.94 kg/piece

Specific CO2 emissions

Unit carbon dioxide load paired with 56.65 tonnes/day total

SOURCED [S30] Values come from a single gate-to-gate Bangladesh T-shirt manufacturing study (published 2024-12-03). They demonstrate per-piece accounting across gas, oil and electricity, not a transferable baseline for Cameroon or GFT.

9.3 EMPIRICAL GARMENT BENCHMARKS ILLUSTRATE METHOD RATHER THAN UNIVERSAL INTENSITY

When GFT designs the performance-management system for its Cameroon programme, **Exhibit 38**, p. 140 serves as a structural template for commissioning the site ledger rather than a borrowed target. [S18] [S30] A Cameroonian plant faces a different

ambient temperature and humidity profile in Douala or Garoua, a different balance between grid power and backup diesel generation, and a product mix combining woven workwear, uniforms and casualwear. [R06] [S25] Under GHG Protocol Scope 2 rules, purchased electricity emissions depend on the local grid or contractual instruments, whereas on-site fuel combustion for steam or standby power enters Scope 1. [S19] Physical megajoules per accepted piece also vary with seam length, stitch density, fabric weight, pressing specification and batch size. [S29] [S30] GFT therefore requires each garment line to build its own metered baseline by product family before setting reduction targets. [S18] [S29]

9.4

Machine and facility loads need separate meters

Relying on a single main utility bill at the factory gate leaves engineers unable to tell whether a monthly spike in kilowatt hours per piece came from overtime sewing, leaking steam traps, chiller staging or unscheduled rework. [S18] [S24] ISO 50001:2018 requires an organisation to identify significant energy uses, determine the variables governing them, and establish energy performance indicators tracked over time. [S18] In a garment plant, meeting that standard requires disaggregating the main electrical incomer and fuel supply into end-use submeters separating conversion machinery from shared building utilities. [S24] [S30]

9.5 SUBMETERING SEPARATES DIRECT GARMENT CONVERSION FROM SHARED PLANT UTILITIES

The Bangladesh T-shirt study separated machinery, steam generation and air-compressor sections to evaluate where energy and emissions concentrate and where upgrades yield measurable savings. [S30] That breakdown showed that steam generation produced the highest carbon dioxide emissions in the facility, while the compressor section produced the lowest direct share of emissions, and machinery upgrades offered an energy-saving potential of 22 to 70 percent within the machinery section. [S30] In an Ethiopian energy audit of the MAA garment and textile plant in Mekelle, researchers similarly disaggregated boilers, thermic fluid heaters, air compressors and lighting, identifying 15 conservation measures with an estimated annual saving potential of around US$214,600 against nearly US$98,300 of investment, a 7-month payback in that facility. [S0902] Both studies confirm that actionable conservation begins when end uses are measured separately rather than pooled into overhead. [S30] [S0902]

For GFT's garment-floor ledger, **Exhibit 39**, p. 142 defines the submetering hierarchy across eight zones: cutting and spreading, sewing lines, steam generation, pressing tables, compressed air, Heating, Ventilation, and Air Conditioning (HVAC), lighting, and wet garment finishing. [S24] [S28] [S30] Each zone requires an explicit physical unit, a metered boundary and a defined allocation driver. [S24] [S29]

EXHIBIT 39 / SUBMETERING SPECIFICATION BY GARMENT END USE

End-use metering reveals the garment plant's real loads

Functional zone	Metered boundary	Primary unit	Allocation driver to product	Primary control variable
Cutting and spreading	Distribution board feeding spreaders, straight/automatic cutters and vacuum tables	kWh	Cut-bundle standard allowed minutes or cut fabric mass (kg)	Vacuum table idle run-time and marker utilisation
Sewing assembly lines	Line-level electrical submeter per modular or progressive sewing line	kWh	Direct attribution to line style batch and accepted pieces	Servo motor standby draw, machine utilisation and rework time
Steam generation	Fuel flowmeter, feedwater meter, boiler electricity and header steam meter	MJ fuel, m3 water, kg steam	Metered steam flow to pressing vs garment washing headers	Boiler efficiency, flue-gas temperature and blowdown rate
Pressing and ironing	Branch steam flowmeter and electrical submeter for vacuum/heated bucks	kg steam, kWh	Pressed accepted pieces weighted by style pressing time	Steam trap leakage, header insulation and re-pressing rate
Compressed air	Compressor package kWh meter, main header flowmeter and pressure transducer	kWh, Nm3 air	Active pneumatic machine hours and leak-adjusted line share	Header pressure (bar), off-shift leak flow and nozzle purge control
HVAC and ventilation	Chiller, evaporative cooler and exhaust-fan electrical submeters	kWh	Floor area and shift operating hours per production hall	Wet-bulb setpoint, filter pressure drop and shift scheduling
Task and hall lighting	Lighting circuit submeters by production bay and inspection zone	kWh	Active shift hours per bay divided by accepted pieces	Lux level at needle/inspection table and occupancy switching
Wet garment finishing	Dedicated water meter, steam branch, chemical log and dryer energy meter	litres, kWh, kg steam, g chemicals	Direct attribution to wet-finished lots and accepted washed pieces	Liquor ratio, bath sequence, extraction moisture and wash RFT

DERIVED [S24] [S28] [S30] [S0901] Derived by combining Higg FEM 4.0 separate tracking rules (S24), DOE compressed-air audit boundaries (S28), garment end-use disaggregation in S30 and garment steam-system loss boundaries in S0901.

9.6 STEAM GENERATION AND PRESSING REQUIRE DEDICATED THERMAL AND DISTRIBUTION CHECKS

While sewing machines dominate floor space, thermal demand in pressing, finishing and washing frequently dominates the energy and carbon ledger. [S30] [S0901] In the 2024 Bangladesh T-shirt study, the authors identified a 25 percent energy-saving potential in steam generation by employing an electric steam generator. [S30] Whether

an electric steam generator reduces emissions or cost in Cameroon, however, depends on the grid emissions factor, power reliability and tariff structure relative to combustion fuels, evaluated under Scope 2 rules and site conditions. [S19] [S25]

Even before changing the heat source, garment steam systems suffer large thermal losses between boiler burner and pressing buck. [S17] [S0901] A study of 15 garment and textile factories in Bangladesh published in 2021 found that average steam generation efficiency was 76 percent, and identified ironing alongside dyeing as the most heat-intensive processes. [S0901] Maximum generation heat loss occurred through dry flue gas at the stack, while in distribution most heat was lost through steam lines and in-process leaks. [S0901] Daily, 694 gigajoules of heat passed away through the studied steam systems, causing 13 tonnes of fuel wastage and 31 tonnes of greenhouse-gas emissions per day, while thermodynamic optimisation could raise efficiency by almost 3.0 percentage points. [S0901]

The U.S. Department of Energy process-heating sourcebook and steam tip sheet confirm that a systems review must inspect the thermal chain from burner to end use before sizing replacement equipment. [S17] [S27] On a garment floor, failed steam traps, bare headers above sewing bays and unreturned condensate waste fuel and water while rejecting heat into the workroom, raising HVAC cooling loads. [S01] [S17] [S0901] Submetering feedwater, fuel and branch steam flow lets utilities engineers track evaporation ratios daily and isolate distribution leaks during shift breaks. [S18] [S0901]

9.7

Compressed air is a system efficiency question

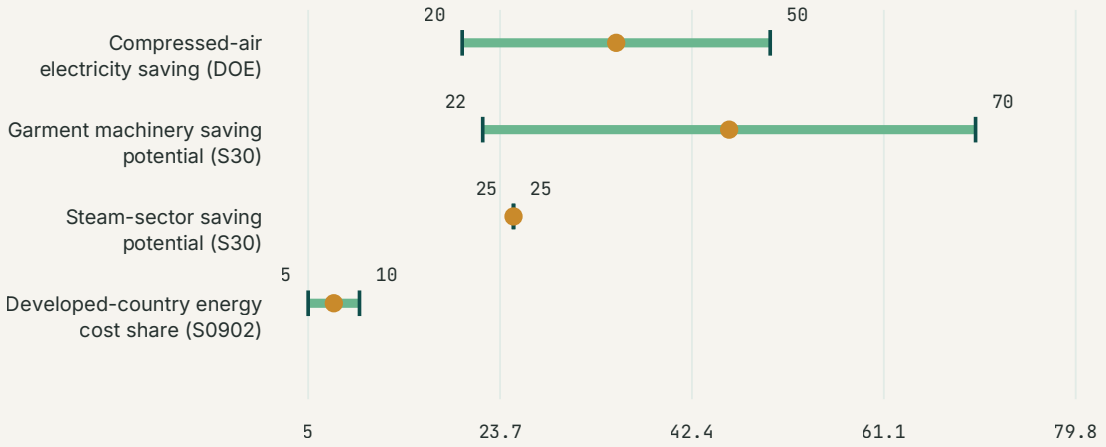
Compressed air powers thread trimmers, presser-foot lifters, pocket welters, buttonholers, spreading clamps and cleaning nozzles across garment lines. [S28] [S30] Because compressed air is clean and convenient at the needle point, supervisors often treat it as free once the compressor is installed. [S28] In energy terms, however, compressed air is typically the most expensive motive utility in a plant because most electrical input converts into waste heat at the compressor and aftercooler rather than mechanical work at the actuator. [S28]

9.8 PNEUMATIC DEMAND ON THE GARMENT FLOOR MUST BE AUDITED FROM COMPRESSOR TO POINT OF USE

The U.S. Department of Energy sourcebook reports that energy savings from compressed-air system improvements can range from 20 to 50 percent or more of electricity consumption in applicable systems. [S28] As **Exhibit 40**, p. 144 illustrates alongside other published garment conservation ranges, a 20 to 50 percent saving potential is an investigation range, not an automatic deduction claimed without measurements. [S28] [S30] Realising any portion of that range requires treating the compressor room, dryer, receiver, piping ring main, filter-regulators and sewing solenoids as one system. [S28]

EXHIBIT 40 / PERCENT REPORTED RANGE IN SOURCE CONTEXT

Published conservation potentials span wide ranges that require site audits



SOURCED [S28] [S30] [S0902] Each bar shows a distinct published range from its respective source: DOE compressed-air system electricity savings (20 to 50 percent, S28), Bangladesh T-shirt machinery energy saving potential (22 to 70 percent, S30), Bangladesh steam-sector electric generator saving potential (single point 25 percent represented at low=mid=high, S30), and developed-country energy share of total production cost (5 to 10 percent, contrasted with higher shares in developing countries, S0902). Not additive and not a GFT forecast.

What **Exhibit 40**, p. 144 cannot establish is how much electricity a Cameroonian plant will save before its baseline equipment is metered. [S28] [S30] If a newly built facility installs direct-drive servo sewing machines with electric thread trimmers and lifters instead of pneumatic actuators, its baseline air demand will already be low, shifting focus toward cutting-room vacuum tables and finishing presses. [S28] [S30] Conversely, if a plant operates pneumatic overlockers, pocket setters and manual lint-blowing guns, unmanaged air leaks and excessive header pressure can make the compressor package one of the largest continuous electrical loads on site. [S28] [S0902]

9.9 LEAK DETECTION, PRESSURE TRIM AND SEQUENCING PRECEDE COMPRESSOR CAPITAL

Three operational faults account for most avoidable compressed-air electricity on a garment floor: leakage across quick-connect couplings and polyurethane tubing under sewing tables, artificial demand from running headers at 7 or 8 bar (illustrative header pressure) when solenoids require only 4.5 to 5.5 bar (illustrative actuator requirement), and open-ended hoses used to blow lint off garments. [S28] Every extra bar of discharge pressure raises compressor power while forcing more air through existing leaks. [S28]

METHOD

Garment-floor compressed-air and drive audit protocol

1. **Boundary and instrumentation.** Install a three-phase kilowatt-hour submeter on the compressor and dryer, a thermal-mass flowmeter on the main header after the receiver, and pressure transducers at discharge and the farthest sewing line. [S18] [S28]
2. **Non-production leak test.** During a shift break with sewing, cutting and pressing equipment switched off and distribution valves open, measure stabilised air flow (`Q_leak`, normal cubic metres per hour) and compressor draw (`P_leak`, kilowatts) required to hold operating pressure, computing `Q_leak / Q_avg_shift`. [S28]
3. **Ultrasonic tagging and repair loop.** Survey drop legs, filter-regulator bowls, couplings and solenoids with an ultrasonic acoustic detector; tag each leak, replace seals and re-test `Q_leak` before evaluating compressor upgrades. [S28]
4. **Pressure drop and header trim.** Measure pressure drop (`Delta_P`) between receiver and the farthest pneumatic station during peak assembly; replace undersized hoses if `Delta_P` exceeds 0.3 to 0.5 bar (illustrative threshold), then step down discharge pressure in 0.2 bar increments while verifying error-free thread trimming. [S28]
5. **Sewing motor standby check.** Clamp-meter a sample of lockstitch, overlock and flatlock machines during bundle handling to verify that brushless servo drives drop to near-zero standby wattage when the treadle is released. [S29] [S30]

Applying this method ensures that capital proposals for variable-speed compressors or automated heads are judged against a leak-repaired baseline. [S18] [S28] It also protects product quality: oil or moisture carryover from poorly maintained air dryers stains garments at the needle point, triggering solvent spotting or re-washing. [S28] [S37]

9.10

Rework multiplies resource use without adding accepted pieces

In wet dyeing, right-first-time processing is recognised as a primary resource lever because re-dyeing a faulty batch consumes extra water, steam and chemicals. [S37] The same law governs the garment assembly floor, even though factory accounting rarely records it. [S24] [S37] When a garment fails inline or end-of-line inspection because of skipped stitches, puckered seams, asymmetric collars, broken needles, oil spots or scorching at the pressing buck, the piece enters a rework loop or is scrapped. [R29] [S37]

9.11 RIGHT-FIRST-TIME ASSEMBLY GOVERNS ELECTRICITY, STEAM AND COMPRESSED AIR PER PIECE

Consider what happens physically when a sewn garment is routed to repair or rejected at final audit. [S37] First, every watt-hour of cutting vacuum, sewing electricity, task lighting, ventilation and compressed air already expended on that garment remains locked in the metered numerator. [S24] [S30] Second, unpicking seams, re-sewing panels, spotting stains with solvents or steam guns, and re-pressing the

repaired garment consume additional electricity, steam and compressed air. [S30] [S0901] Third, if the garment is permanently rejected as scrap, the accepted-output denominator does not advance; the accepted pieces in that shift must carry the utility burden of the failed unit. [S29] [S37]

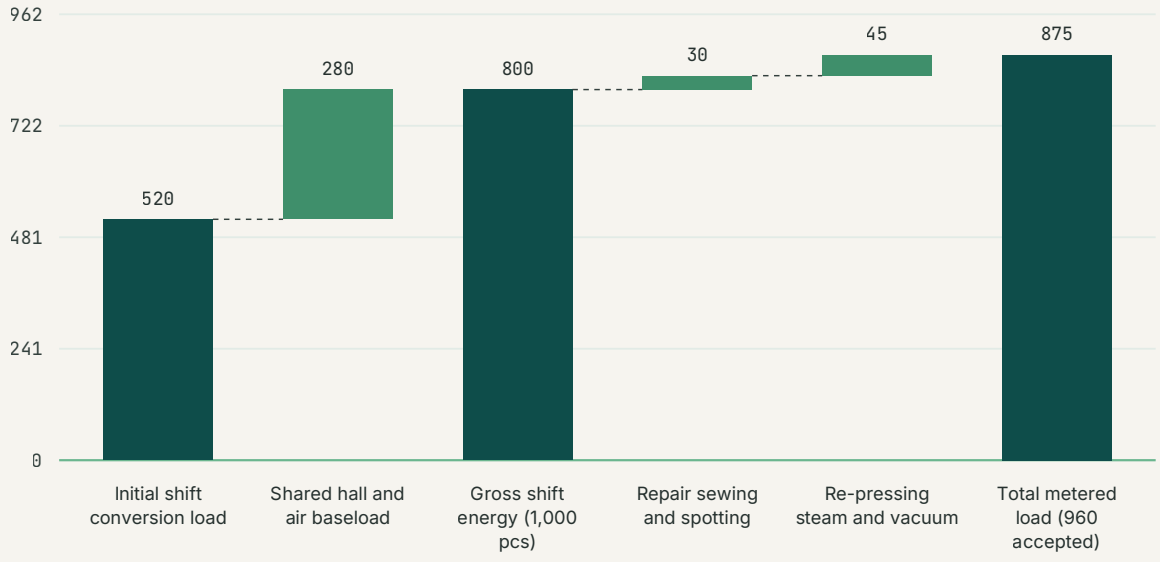
This mechanism connects upstream fabric inspection and inline needle quality directly to energy and water intensity per piece. [R29] [S37] In GFT's shared evidence base, manual fabric defect inspection is reported as 60 to 70 percent accurate, missing 20 to 30 percent of defects, whereas computer-vision inspection achieves above 90 percent accuracy across more than 40 defect types at speeds up to 60 metres a minute. [R29] When undetected fabric slubs, shade bars or holes pass through cutting into sewing bundles, operators sew defective panels that are rejected only at final inspection, wasting both fabric and assembly utilities. [R29] [S37] Catching fabric faults before spreading and catching stitch defects at the needle therefore act as direct resource controls. [R29] [S37]

9.12 LINE LOGS MUST RECONCILE GROSS BUNDLES, REPAIR LOOPS AND ACCEPTED OUTPUT

If a garment factory divides monthly electricity and steam bills by gross pieces sewn (counting a repaired garment twice or including rejected pieces in output), specific energy consumption is artificially deflated. [S29] [S37] As shown in **Exhibit 41**, p. 146, reconciling the energy ledger from gross output to net accepted output after rework exposes the utility penalty of quality failure. [S29] [S37]

EXHIBIT 41 / ILLUSTRATIVE SHIFT LOAD (KWH EQUIVALENT)

Accepted pieces expose the resource cost of rework



ILLUSTRATIVE Illustrative shift energy reconciliation constructed to demonstrate the accounting method. Assumes a 1,000-piece shift bundle input, 800 kWh base conversion and utility load, 75 kWh extra repair-loop and re-pressing energy for 120 reworked pieces, and 40 permanently rejected pieces (960 net accepted pieces). Not a measured GFT result.

The waterfall in **Exhibit 41**, p. 146 shows why gross ratios mislead managers. [S29] [S37] Dividing 800 kilowatt hours of initial conversion and hall baseload by 1,000 gross bundles suggests an illustrative intensity of 0.80 kilowatt hours per piece. Once

75 kilowatt hours of repair sewing, stain spotting and re-pressing steam are added to the numerator and 40 scrapped garments are removed from the denominator, the 875 kilowatt hours spread across 960 accepted garments yield 0.911 kilowatt hours per accepted piece, an illustrative penalty of nearly 14 percent above the naive figure.

WORKED EXAMPLE

Shift-level reconciliation of electricity, steam and rework on a woven shirt line

Consider an illustrative 8-hour shift on a modular sewing and pressing line producing woven cotton shirts (all figures are illustrative assumptions chosen to show the arithmetic, not observations from a GFT facility): [S29] [S37]

- **Production counts (illustrative):** The cutting room issues `N_gross = 1,000` shirts. At quality gates, `N_rft = 840` shirts pass right first time. Of the `160` defective shirts, `N_rep = 120` pass re-inspection after unpicking, re-sewing, steam spotting and re-pressing, while `N_Scrap = 40` fail permanently. Net accepted output is `N_acc = 840 + 120 = 960` pieces (illustrative first-pass yield `84.0` percent, final acceptance `96.0` percent). [S37]
- **Metered shift energy (illustrative):** Submeters record `E_mach = 310` kWh for cutting and sewing, `E_steam = 210` kWh-equivalent of steam for first-pass pressing (`520` kWh conversion load), and `E_base = 280` kWh for allocated compressed air, lighting and ventilation (`800` kWh initial subtotal). Rework sewing and second-pass pressing add `E_rework_elec = 30` kWh and `E_rework_steam = 45` kWh-equivalent (`75` kWh rework energy), giving `E_total = 800 + 75 = 875` kWh-equivalent. [S29] [S30]
- **Flawed gross-pass ratio (illustrative):** Counting repaired pieces as extra volume (`1,000 + 120 = 1,120` passes) gives `875 / 1,120 = 0.781` kWh/pass (illustrative), making a high-rework shift look artificially efficient. [S29] [S37]
- **Unadjusted bundle ratio (illustrative):** Dividing initial energy (`800` kWh) by initial bundles (`1,000` pieces) gives `800 / 1,000 = 0.800` kWh/piece (illustrative). [S29]
- **GFT accepted-piece intensity (illustrative):** Dividing total energy by net accepted pieces gives `I_acc = 875 / 960 = 0.9115` kWh/accepted piece (illustrative), while diagnostic intensity per right-first-time piece is `I_rft = 875 / 840 = 1.0417` kWh (illustrative). [S29] [S37]
- **Decision consequence (illustrative):** Locking the KPI to `I_acc = 0.9115` kWh/accepted piece shows the supervisor that raising right-first-time yield from `84` percent toward `98` percent (illustrative target) cuts unit energy intensity by over `12` percent without capital outlay. [S29] [S37]

9.13

Utilisation changes fixed energy per accepted piece

Unlike a batch dyeing machine whose water fill scales with load, a garment hall carries a fixed energy baseload whenever the building is open. [S18] [S29] General lighting, air-handling fans, cooling loops, cutting-room dust extraction, boiler radiation losses and compressed-air leakage draw kilowatt hours and fuel even when sewing needles stop. [S28] [S29] [S0901]

9.14 STANDBY AND BUILDING BASELOADS PENALISE UNBALANCED OR UNDERUTILISED LINES

Benchmarking research across textile companies demonstrates that specific energy consumption (SEC, energy per unit produced) varies strongly with throughput because fixed facility energy is diluted across more units at high utilisation and concentrated across fewer units during stoppages. [S29] If shift energy follows `E_shift = E_fixed + e_var * N_acc` (illustrative equation, where `E_fixed` is shift baseload, `e_var` is variable energy per garment, and `N_acc` is accepted pieces), then `SEC = (E_fixed / N_acc) + e_var`. [S29] Whenever stoppages, late bundles, breakdowns or unbalanced workstations reduce `N_acc`, the fixed term `E_fixed / N_acc` rises sharply. [S18] [S29]

In Cameroon, historical evidence from the incumbent sector underscores why utilisation and power continuity are primary efficiency variables. [R12] [S25] According to a July 2023 report in GFT's evidence register, CICAM's capacity utilisation stood at 33.7 percent at Garoua, 48.9 percent at CICAM 1 and 10.83 percent at CICAM 2, with underutilisation costing about CFAF 2 billion in 2020. [R12] Those figures describe a third-party enterprise and are not a forecast for GFT, but they illustrate a vital rule: a factory running at 33.7 or 48.9 percent of capacity cannot achieve competitive unit energy intensity if its boilers, compressors and hall utilities remain energised for full shifts. [R12] [S29]

> **WARNING**
>
> **Contextual boundary on Cameroonian utilisation and power-sector records**
>
> Inherited evidence entry R12 on CICAM capacity utilisation (33.7 percent at Garoua, 48.9 percent at CICAM 1 and 10.83 percent at CICAM 2 in a July 2023 report) and World Bank reporting on the Cameroon Power Sector Reform Program approved in August 2023 (S25) provide macro-industrial context only. [R12] [S25] They do not establish a site electricity reliability factor, a grid emission factor or an expected utilisation rate for a new garment plant. [S19] [S25] Before GFT commits capital to electric boilers, heat pumps or automated cutting rooms in Cameroon, site engineering must log voltage stability, outage frequency, generator fuel draw and modular turn-down capability so idle baseloads can be shed when a bay is unscheduled. [S18] [S25]

9.15 OEE, LINE BALANCING AND SPECIFIC ENERGY CONSUMPTION BELONG IN ONE REVIEW

Because fixed baseload couples throughput to unit intensity, engineers should review specific energy consumption alongside Overall Equipment Effectiveness (OEE) and line balance efficiency. [S18] [S29] When a sewing line suffers a bottleneck at collar attachment or sleeve setting, downstream operators and pressing tables wait in standby while lighting, HVAC, vacuum blowers and steam headers consume energy. [S29] [S0901] Balancing workstation cycle times, staging pre-cut bundles before shift start, and grouping pressing into continuous campaigns allow the plant to shut down boiler branches and compressor zones when not under full load. [S18] [S28] [S0901]

9.16

Wet garment finishing belongs inside the piece boundary

A garment factory performing only dry cut, make, trim and steam pressing uses freshwater primarily for boiler make-up, evaporative cooling, spot cleaning and sanitation. [S01] [S24] As soon as the product requires garment washing, piece dyeing, enzyme bio-polishing, stone washing, bleaching or denim finishing, the plant crosses into the wet-processing boundary. [S02] [S07] Failing to isolate wet-finished garments from dry-assembled garments corrupts both water and energy KPIs: averaging laundry water across all sewn pieces understates the intensity of washed styles while making dry styles appear water-intensive. [S24] [S29]

9.17 GARMENT WASHING INTRODUCES DYEHOUSE-CLASS WATER, CHEMICAL AND THERMAL DUTIES

Industrial garment washing uses rotary drum washers, hydro-extractors and tumble dryers that consume process water, chemicals, steam and drive power on every batch. [S01] [S02] [S07] Project evidence documented by the United Nations Industrial Development Organization (UNIDO) under the MED TEST II programme in Tunisia illustrates both the scale of garment-washing water demand and the need to separate projections from verified baselines. [S07] At New Amico, a jeans manufacturer in Tunisia, introducing two ozone-washer machines and three E-flow nano-bubble machines was projected to reduce water consumption for washing jeans by 13 litres per piece. [S07]

EXHIBIT 42 / UNIDO PROJECT RECORD (TUNISIA JEANS CASE, 2018)

Garment washing belongs in litres and energy per accepted piece

13 L/piece

Reported water reduction

Projected water reduction for washing jeans using three E-flow machines

3 E-flow units

Low-liquor technology unit

Nano-bubble finishing machines paired with ozone washing in the UNIDO case

1 pair of jeans

Accounting denominator

Demonstrates per-piece water reporting for wet-finished garments

Case projection

Evidence classification

Must be separated from site-measured baseline and post-audit verification

SOURCED [S07] Sourced to UNIDO's 2018-03-22 report on New Amico in Tunisia (S07). The 13 litres per piece figure is a project-specific reduction associated with three E-flow machines on denim jeans, not a sector baseline or a guaranteed saving for GFT.

As **Exhibit 42**, p. 150 highlights, a garment-washing intervention measured in double-digit litres per pair of jeans exceeds the entire freshwater intake of a dry sewing line per piece. [S07] [S24] At the same time, GFT's evidence rules require discipline when reading cases like New Amico. [S07] [S23] The UNIDO account states what three E-flow machines will allow that Tunisian facility to save on its jeans; it does not establish that another laundry will save 13 litres per piece, nor does it replace post-commissioning verification of water, electricity, drying heat and effluent load. [S07] [S33]

Wet garment finishing also creates a chemical and wastewater compliance obligation under the ZDHC Wastewater Guidelines and MRSL framework. [S32] [S33] Permanganate sprays, bleaches, pumice, enzymes, brighteners and softeners discharged from washing drums enter the effluent stream alongside lint and suspended solids. [S01] [S33] Every wet-finished lot must therefore carry batch records linking chemical formulation and Safety Data Sheet conformance, [S32] freshwater intake per accepted washed piece, [S07] extraction moisture, dryer thermal energy [S17] and wastewater testing. [S33]

9.18 DRY-ONLY, OWNED WET-FINISHING AND OUTSOURCED WASHING ROUTES NEED DISTINCT LEDGERS

In GFT's Cameroon model, garment styles follow three distinct finishing routes: 1. **Route A (Dry cut-make-trim and steam press only):** Shirts, trousers or T-shirts cut and sewn from finished fabric, pressed with steam and packed without wet washing. [S24] [S30] The owned ledger tracks cutting and sewing electricity, compressed air, pressing steam, boiler make-up water and rework. [S30] [S0901] 2. **Route B (In-house wet garment finishing):** Garments passing into an owned on-site laundry for enzyme wash, softening, dyeing or denim finishing before drying and pressing. [S07] [S24] Following Higg FEM 4.0 rules, the laundry is submetered as a separate boundary so its litres, steam, dryer kilowatt hours and chemicals per washed piece are reported explicitly alongside the dry assembly score, never blended into Route A averages. [S24] 3. **Route C (Outsourced wet garment finishing):** Garments sewn in-house, sent to an external commission laundry for washing, and returned for packing. [S24] Claiming low owned water intensity simply because washing is subcontracted outside the fence line is a boundary shift, not an environmental improvement. [S23] [S24] GFT's ledger flags Route C styles as carrying a partnered wet-finishing boundary and requires batch water, energy, chemical and ZDHC effluent records from the subcontractor. [S24] [S33]

9.19

The daily dashboard should prompt action at line level

Collecting submeter pulses and quality logs has no operational value if numbers sit in a monthly spreadsheet viewed after utility bills are paid. [S18] Under ISO 50001:2018, energy indicators must be integrated into operational control and reviewed at defined intervals against baselines and relevant production variables. [S18] [S29] In GFT's architecture, the garment floor links daily shift supervision to weekly utility engineering through a tiered indicator cascade. [S18] [S24]

9.20 LINE-LEVEL INDICATORS CONNECT SHIFT SUPERVISION TO WEEKLY UTILITY ENGINEERING

At shift end, a line supervisor does not control grid carbon factors or boiler procurement, but directly controls bundle flow, first-pass quality, machine idle time, blow-gun misuse and steam-table shutdown during breaks. [S28] [S37] [S0901] The daily line huddle tracks five metrics on a shift card:

- **Accepted pieces released (`N_acc`) and first-pass yield (`FPY`, percent):** Counted at the end-of-line quality gate, separating right-first-time garments from repaired units and rejects. [S37]
- **Line electrical intensity (`kWh / accepted piece`):** Metered at the line distribution board and compared against the style baseline at the shift's utilisation level. [S29] [S30]
- **Pressing steam intensity (`kg steam / accepted piece`):** Metered at the finishing branch header, flagging failed steam traps or excessive re-pressing immediately. [S30] [S0901]

- **Compressed-air off-shift floor (`Nm3/h` or `kW` during break):** Checked during the mid-shift break when production stops, exposing new hose or coupling leaks the day they occur. [S28]
- **Wet-finishing intensity (`L / accepted washed piece` and `kWh / accepted washed piece`):** Tracked per laundry batch for Route B styles, paired with wash right-first-time release. [S07] [S24]

When any daily indicator breaches its control band, the exception escalates to the weekly utility and quality review owned by the garment-plant manager, maintenance lead and sustainability engineer. [S18] That weekly review cross-checks submeter totals against main meters, investigates whether variance stemmed from product mix, low utilisation, [R12] rework spikes [S37] or equipment degradation, [S28] [S0901] and assigns corrective actions. [S18] [S29]

9.21 NORMALISATION AND EVIDENCE STATUS PROTECT MANAGEMENT DECISIONS FROM FALSE VARIANCE

Comparing a shift producing heavy cargo trousers with enzyme washing against a shift producing basic T-shirts without normalisation generates false alarms. [S29] [S30] Following specific-energy benchmarking methods, [S29] GFT's ledger normalises line electricity and steam against standard allowed minutes (SAM), seam count or garment mass, while stratifying dry styles (`Route A`) separately from wet-finished styles (`Route B` and `Route C`). [S24] [S29] Every dashboard tile also carries an explicit evidence status tag (`measured`, `derived`, `estimated` or `illustrative`) under LCA data integrity rules, [S23] ensuring that ramp-up estimates are never confused with verified meter observations. [S18] [S23]

GFT NOTE

Practical recommendation for GFT's Cameroon garment programme

Because GFT's initial Cameroon operating concept centres on garment manufacturing and finishing while upstream spinning, weaving and dyeing capacities are built or partnered across the cotton value chain, [R06] [R07] the garment floor is the first boundary GFT will instrument directly. [S24] GFT should embed four rules into the factory specification before procurement: 1. **Procure electronic servo drives and electric actuators by default:** Specify direct-drive brushless servo sewing motors and electric thread/foot actuators wherever compatible with the garment portfolio, eliminating clutch-motor idle draw and minimising pneumatic demand. [S28] [S30] 2. **Wire and pipe submeters at construction stage:** Install electrical submeters by sewing line, cutting bay, compressor room, HVAC and lighting circuit, alongside branch steam and water meters for pressing and garment-washing drums, following **Exhibit 39**, p. 142. [S18] [S24] [S0901] 3. **Lock the denominator to accepted pieces right first time:** Configure the execution system so line KPIs divide shift electricity, steam, compressed air and water by net accepted pieces released to packing, displaying the rework penalty on every shift report. [S29] [S37] 4. **Ring-fence wet garment finishing:** Meter any in-house laundry as a separate wet-processing boundary (Route B) and require batch resource and ZDHC wastewater records from any outsourced laundry (Route C) before publishing sustainability figures. [S07] [S24] [S33]

By binding electricity, steam, compressed air, wet washing and rework into a single per-piece accounting system, the garment plant closes the final process loop of Part II. [S24] [S30] Part III turns from individual process boundaries to plant-wide reduction systems, beginning with how water treatment and reuse must match recycled water quality to the exact duty of the next production bath. [S06]

A garment that is sewn twice or washed twice carries two utility bills inside one piece, and only an accepted-unit ledger tells the truth.

CHAPTER SOURCE NOTES

S24 Sustainable Apparel Coalition. 2022.

S30 Springer Nature, Energy Efficiency. 2024-12-03.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

S0902 Springer Nature, Energy Efficiency. 2022-08-01.

S07 United Nations Industrial Development Organization. 2018-03-22.

S37 Emerald Publishing Limited. 2019.

R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.

R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.

S18 International Organization for Standardization. 2018.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S23 Textile Exchange. 2025-08-07.

S25 World Bank. 2025-06-25.

S19 GHG Protocol. 2015.

S28 United States Department of Energy and Compressed Air Challenge. 2003.

S0901 Springer Nature, Energy Efficiency. 2021-01-23.

S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.

S27 United States Department of Energy, Advanced Manufacturing Office. 2012.

R29 MDPI; industry inspection literature. Publication date unrecorded; inherited source-text check.

R12 Business in Cameroon. Publication date unrecorded; inherited source-text check.

S02 European Commission Joint Research Centre. 2023.

S33 ZDHC Foundation. 2024.

S32 ZDHC Foundation. 2023.

S06 MDPI, Processes. 2019-01-11.

GREEN FUTURE TECH

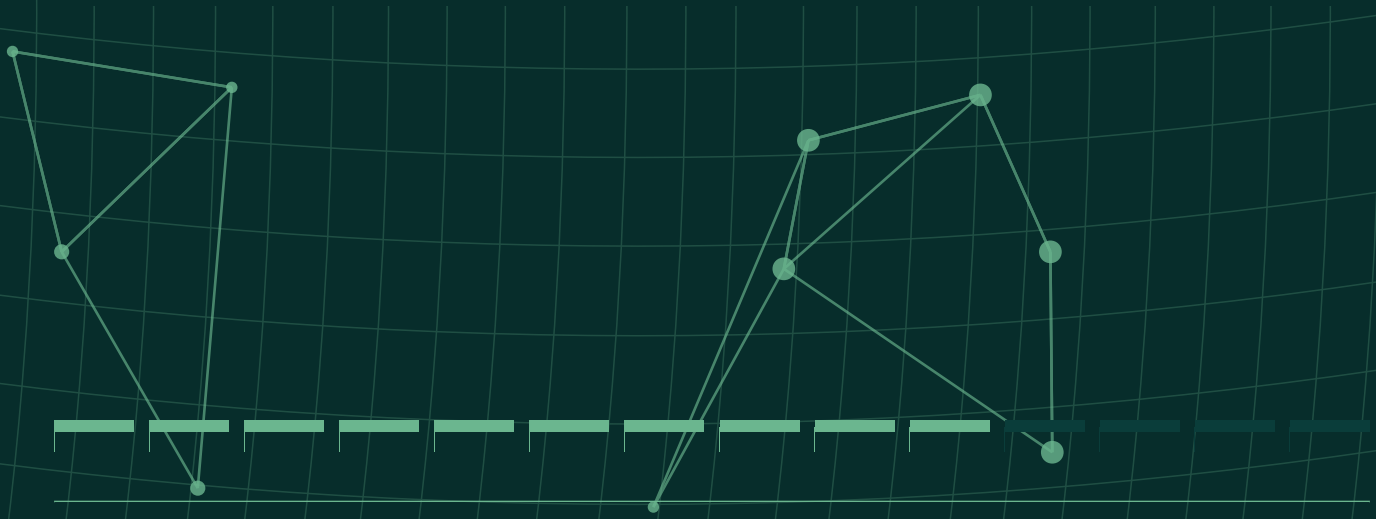
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10

PART III: REDUCTION IS A SYSTEM / TREATMENT AND CIRCULATION

Reuse works when water quality is matched to the next duty

A reuse system is a production process with its own energy, chemistry, losses and quality release, not a free source of water.



CHAPTER 10
DECISION TEST

A reuse system is a production process with its own energy, chemistry, losses and quality release, not a free source of water.

Water reuse reduces a textile factory's net environmental burden only when each recovered stream is segregated, matched to its receiving operation, and credited after treatment electricity, chemicals, concentrate, sludge and quality-induced reprocessing. [S01] [S06] Under-treatment can introduce hardness, alkalinity, salt or colour into sensitive dye baths and cause corrective work. Over-treating every stream through ozonation and reverse osmosis adds electricity demand and a saline reject. [S02] [S06] [S37] [S1001] For GFT's Cameroon textile programme, moving wet processing onshore makes water circulation a controlled manufacturing stage. The inherited sector baseline records about 95 percent of cotton fibre exported raw and 5 percent processed locally, with a national target of 50 percent local processing by 2030. [R06] [R07] This chapter defines the required segregation, quality release, mass and energy balances, residual governance and sampling before comparing partial reuse with zero liquid discharge. It is an engineering framework, not legal, regulatory or investment advice.

10.1

Segregation preserves treatment options

A textile wet-processing plant discharges distinct process liquors whose volume, temperature, organic load, salinity and chemical toxicity can vary substantially by process and operating sequence. [S01] [S02] In the literature review compiled by VTT, wet processes account for 60 to 90 percent of total textile water use. [S03] When floor drains empty into one equalisation basin, low-salinity cooling water and final rinses are contaminated by spent reactive dyebaths, desizing liquors and mercerising caustic washes, forcing the treatment plant to address the combined contaminant profile. [S01] [S02] [S1003]

IFC's environmental, health and safety guidelines for textile manufacturing place source segregation at the front of wastewater design, distinguishing chemical oxidation for non-biodegradable high-load chemical oxygen demand (COD) streams, chemical precipitation, coagulation and flocculation for heavy-metal streams, and reverse osmosis for highly coloured or high total dissolved solids (TDS) streams. [S01] The same logic applies inside preparation and dyeing halls. [S02] [S38] Desizing effluents carry biochemical oxygen demand (BOD5) and COD loads representing 35 to 50 percent of a composite mill's organic load, with COD concentrations reaching up to 20,000 milligrams per litre when starch, modified starch or synthetic sizes are stripped from grey fabric. [S01] Mixing that concentrated stream with clean cooling water or bleach rinses can compromise recovery. Ultrafiltration can recover suitable polyvinyl alcohol or carboxymethyl cellulose formulations, but the BAT reference excludes some synthetic sizes, including certain polyacrylates, so recovery requires formulation-specific validation. [S01] [S02]

Segregation begins with a drain-level manifold separating four classes at the machine boundary: [S01] [S02] 1. **Non-contact utility streams:** Compressor cooling, stenter cooling rollers and indirect heat-exchanger water pick up sensible heat without chemical contamination and return directly to warm process makeup tanks after temperature and conductivity checks. [S01] 2. **Low-contamination wash and rinse fractions:** Later compartments of countercurrent washing ranges and final peroxide-bleach rinses cascade backward into upstream desizing or initial scouring baths

without membrane desalination. [S01] [S38] 3. **High-alkali mercerising washes:** Cotton treated with concentrated sodium hydroxide generates hot alkaline rinse water suitable for evaporative or membrane alkali recovery, subject to colour checks on yarn-dyed cloth. [S01] 4. **High-salt and high-colour dyehouse drains:** Spent reactive and disperse dyebaths, printing-belt wash waters and initial soap-off baths carry unfixed dye and electrolytes requiring dedicated treatment. [S01] [S31]

In cotton batch dyeing with reactive dyes, salt additions range from 20 to 80 percent of fabric weight, producing dyebath effluent salt concentrations of 2,000 to 3,000 parts per million alongside COD values often above 5,000 milligrams per litre. [S01] Laboratory characterisation of conventional reactive yellow dyeing on cotton confirms that high electrolyte and alkali dosing drives elevated effluent TDS, COD and BOD loads unless salt-free or low-salt chemistries are validated. [S31] Because biological treatment and ultrafiltration leave dissolved salts untouched, high-salinity dyebath drains determine whether reverse osmosis or evaporation is needed for closed-loop recycling. [S06] [S1001] Segregating saline drains from low-salt preparation and final rinses confines energy-intensive desalination to the fraction requiring salt rejection. [S01] [S02]

Physical segregation must be paired with accounting segregation. Higg FEM technical guidance requires any site manufacturing both fabric and finished garments to track and report energy and water consumption separately by facility type. [S24] Each segregated header therefore requires its own flow meter, conductivity probe and batch-linked diversion valve so operators can trace any rise in membrane inlet conductivity to the exact machine drain. [S18] [S24] [S1002]

> **GFT NOTE**
>
> Design the drainage and return piping as a segregated manifold before pouring the dyehouse floor slab. Group drains into four valved headers: indirect cooling water, low-salt preparation and final rinses, recoverable caustic mercerising washes, and high-salt or high-colour dyebath and print-wash effluents. Equip each automated diversion valve with an inline conductivity and temperature sensor interlocked to the batch recipe step, so a spent reactive salt bath cannot enter the direct-reuse polishing tank.

10.2

Fit-for-purpose quality prevents a false circularity gain

Recycling water inside a textile mill is an input-quality decision governed by the receiving process, not a waste-disposal target governed by the treatment plant. [S02] [S37] Reclaimed water satisfying a national discharge standard can still cause immediate production failure if routed to an incompatible wet-processing duty, because multivalent cations, residual oxidants, carbonate alkalinity, chromophores and salts interact directly with dye molecules and cellulose functional groups. [S06] [S31] [S37] Evaluating reuse by volumetric recovery while ignoring exhaustion, fixation, shade reproducibility and scaling violates the whole-cycle boundary of this paper. [S36] [S37]

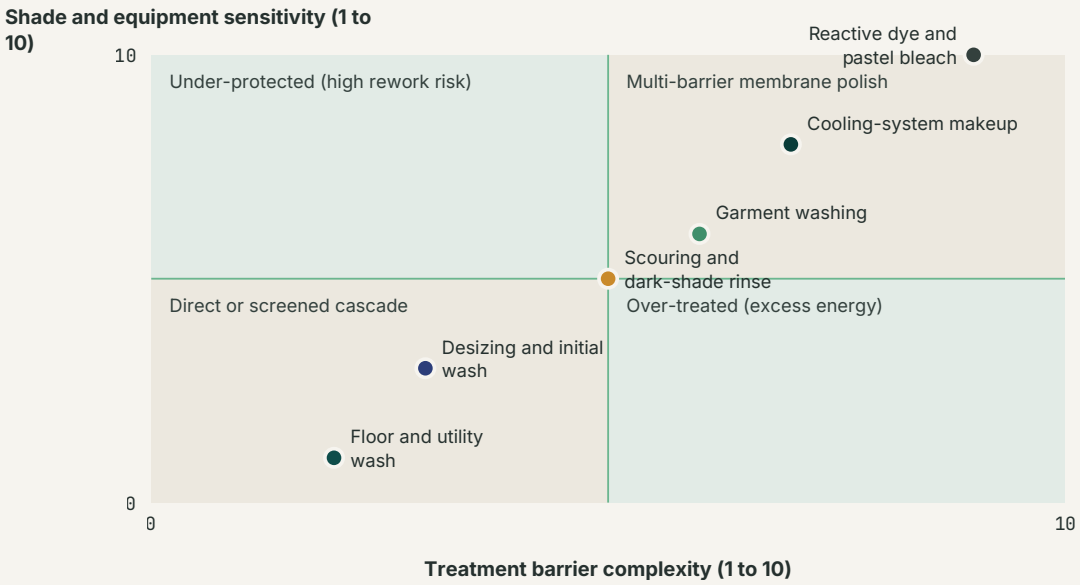
Right-first-time dyeing research demonstrates the empirical sensitivity of cotton dyeing to water quality. [S37] In hard water, dissolved calcium and magnesium ions can form precipitates and dye aggregates. [S37] Across experimental water hardness levels of 10, 40 and 70 German degrees of hardness, higher hardness reduced colour strength and altered lightness, shade and total colour difference in the tested reactive-dye system. Whitish deposits were proposed as an explanatory mechanism, not measured as a separate outcome. [S37] A batch missing its target shade may require shading additions, stripping or full re-dyeing, consuming extra water, thermal energy, auxiliaries and machine time while generating additional effluent. [S37] If a reuse loop saves 30 percent of fresh intake on paper but reduces right-first-time performance, the extra resource load of re-dyed batches must be debited against the reuse account. [S02] [S37]

Water quality matching therefore requires a multi-parameter release gate tailored to each receiving operation. [S01] [S02] Membrane-reuse research on pre-treated textile dyeing wastewater in China illustrates the treatment duty between membrane-bioreactor effluent and a cited reverse-osmosis permeate standard. [S1002] The feed had pH 8.52, COD 80 milligrams per litre, total organic carbon 12 milligrams per litre, suspended solids 0 milligrams per litre, chroma 95 dilution times, iron 0.27 milligrams per litre, manganese 0.06 milligrams per litre, total hardness 422 milligrams per litre as calcium carbonate, and conductivity 8.82 millisiemens per centimetre. [S1002] The cited Chinese textile reuse standard for reverse-osmosis permeate required pH 6.5 to 8.5, COD at or below 50 milligrams per litre, suspended solids at or below 30 milligrams per litre, chroma at or below 25 dilution times, iron at or below 0.3 milligrams per litre, manganese at or below 0.2 milligrams per litre, total hardness at or below 450 milligrams per litre as calcium carbonate, and conductivity at or below 2.5 millisiemens per centimetre. [S1002] Thus COD, chroma and conductivity required substantial removal, while the feed already met the listed hardness, suspended-solids, iron and manganese limits. This comparison defines an RO treatment duty, not a discharge violation. [S1002]

Compliance with that general envelope still does not prove suitability for a critical shade. The feed hardness of 422 milligrams per litre sits below the general RO-permeate ceiling of 450, but the BAT reference recommends no more than 90 milligrams per litre as calcium carbonate for high-quality recycled effluent. [S02] [S1002] S37 also found hardness-dependent shade effects in one reactive-dye system. Receiving limits should therefore be established by paired fabric and dye trials, with softening or sequestering evaluated where necessary. [S37] **Exhibit 43**, p. 159 offers an illustrative screening matrix, not a measured ranking, for matching treatment barriers to downstream shade and equipment sensitivity. [S01] [S02] [S37] [S1002]

EXHIBIT 43 / ILLUSTRATIVE SCREENING SCORE (0 TO 10)

An illustrative duty screen matches treatment barriers to downstream sensitivity



ILLUSTRATIVE [S01] [S02] [S37] [S1002] Illustrative GFT heuristic informed by the cited sources, not measured performance. X: 0 to 2 cascade or screening, 3 to 5 clarification or filtration, 6 to 8 oxidation or UF, 9 to 10 RO and polishing. Y: 0 to 2 no product contact, 3 to 5 upstream wash, 6 to 8 equipment or final rinse, 9 to 10 critical dyeing or pastel work. Integer positions require site validation.

Duties in the lower-left quadrant, such as desizing and initial grey-fabric washing, may accept countercurrent bleach-rinse water after lint screening and control of residual oxidant, subject to the actual size recipe. [S01] [S02] Duties in the upper-right quadrant, notably reactive dyebaths, optical brightening, pastel bleaching and final soft-water rinses, require strict control of hardness, iron, manganese, colour, alkalinity and conductivity. [S06] [S37] [S1002] Routing partially treated effluent into the upper-left quadrant creates rework risk, whereas routing high-purity reverse-osmosis permeate to floor washing can waste pump and ozone electricity on a less sensitive duty. [S06] [S1001] **Exhibit 44**, p. 160 converts the screening logic into candidate controls and source benchmarks. It is not a validated site specification. [S01] [S06] [S37] [S1001] [S1002]

EXHIBIT 44 / CANDIDATE CONTROLS AND SOURCE BENCHMARKS

Reference values inform, but do not replace, a site release gate

Receiving duty	Eligible source & barrier	Critical control parameters	Reference benchmark in sources	Primary failure mode if breached
Desizing & grey wash	Bleach/final rinse cascade + fine screen	SS, pH, residual oxidant, temperature	Reuse bleach rinse in desizing (S01)	Enzyme deactivation or lint redeposition
Mercerising wash & caustic makeup	Segregated mercerising rinse + evaporation/NF	NaOH concentration, colour, suspended fibres	Alkali recovery subject to colour limit (S01)	Shade staining on yarn-dyed woven cloth
Reactive dyeing & pastel bleaching	Bio + O3/UF + RO permeate (plus softening)	Hardness, colour, conductivity, Fe/Mn, pH	Foshan mean primary/secondary RO: CODcr 0.37/0.44 mg/L; hardness 22.04/3.45 mg/L (S06)	Dye precipitation, ΔE failure, catalytic fibre damage
Post-dye countercurrent rinsing	Cascaded later rinses or UF/RO blend	Conductivity, residual colour, total alkalinity	FZ/T 01107-2011 RO reuse: conductivity <=2.5 mS/cm, chroma <=25 (S1002)	Poor wash fastness or back-staining of ground shade
Cooling & utility makeup	Segregated non-contact cooling or RO permeate	Hardness, silica, chloride, microbiological activity	Historical GB/T 19923-2005 in Foshan: Cl- <=250 mg/L, hardness <=450 mg/L (S06)	Heat-exchanger scaling, biofouling or corrosion

DERIVED [S01] [S02] [S06] [S37] [S1001] [S1002] Derived control framework from S01, S02, S06/S1001, S37 and S1002. Foshan values are reported averages for two different permeate streams, not limits or observed ranges. FZ/T 01107-2011 values in S1002 are RO-permeate reuse thresholds, not duty-specific site release limits. GB/T 19923-2005 values are historical benchmarks in the 2019 Foshan study; verify the currently applicable edition and local duties before use. Site limits require paired product trials.

In the Foshan case study, the cited national reuse standard permitted CODcr up to 60 milligrams per litre, colour up to 30 dilution times, hardness up to 450 milligrams per litre and chloride and sulphate up to 250 milligrams per litre each. Reported average primary and secondary reverse-osmosis permeate values were CODcr 0.37 and 0.44 milligrams per litre, colour 0.33 and 0.32 dilution times, hardness 22.04 and 3.45 milligrams per litre, and conductivity 415.84 and 288.60 microsiemens per centimetre. [S06] [S1001] These averages met the cited standard and show substantial hardness and salt removal. They do not prove suitability for every sensitive dye process. GFT's proposed batch ledger therefore requires reuse-tank quality at every dyebath fill and product-specific release trials. [S06] [S31] [S37]

10.3

A treatment train needs mass and energy balances

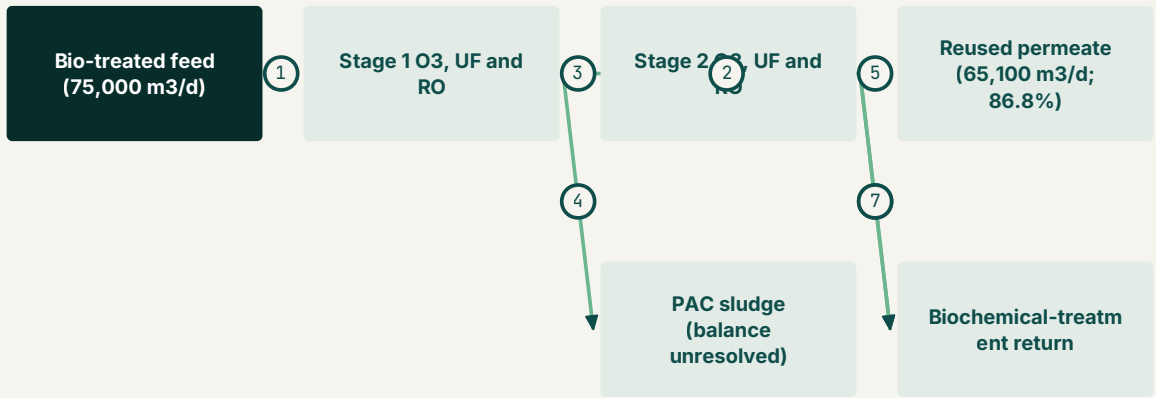
A wastewater reuse plant is a multi-stage separation process whose performance cannot be summarised by a single recovery percentage. [S06] [S1001] Every unit operation requires chemical or electrical inputs, rejects a side stream or backwash flow, and

alters the water passing to the next barrier, so GFT decomposes any headline recovery claim into a closed mass, energy and chemical balance. [S04] [S06] [S1001] [S1003]

The full-scale Foshan study treated 75,000 cubic metres per day of biologically treated effluent, operating 24 hours per day. [S06] [S1001] Stage 1 used polymeric aluminium chloride (PAC) at 80 grams per cubic metre, tube settling, sand filtration, ozonation at 80 to 100 grams per cubic metre (average 90), ultrafiltration below 0.15 megapascals and reverse osmosis at 1.0 to 1.2 megapascals. [S1001] Stage 2 treated 24,750 cubic metres per day of primary concentrate, with average conductivity of 28,236 microsiemens per centimetre, through ozonation at 100 to 120 grams per cubic metre (average 118), filtration, ultrafiltration and reverse osmosis at 1.5 to 2.5 megapascals (**Exhibit 45**, p. 161). [S06] [S1001] This is one documented train, not a design template.

EXHIBIT 45 / CUBIC METRES PER DAY (M3/D)

The simplified Foshan balance separates permeate from unrecovered flow



1. 75,000 m3/d
2. Primary permeate 50,250
3. Primary concentrate 24,750
4. Solids separated
5. Secondary permeate 14,850
6. Unrecovered RO flow 9,900 (derived)
7. Cleaning returns 1,230 (internal)

DERIVED [S06] [S1001] S06 and S1001 are copies of one study. RO balance: 75,000 = 50,250 + 24,750 and 24,750 = 14,850 + 9,900 m3/d. Permeate total is 65,100 m3/d (86.8%); 9,900 is derived by difference, not a metered discharge. Cleaning returns total 3,210 m3/d: 1,500 within Stage 1, 480 to the RO tank and 1,230 to biochemical treatment. Internal returns are not terminal losses. PAC sludge balance remains unresolved.

Inspecting the flow diagram reveals three engineering realities that an 86.8 percent headline omits. [S06] [S1001] First, each barrier performs a distinct separation job. Coagulation, precipitation, sand filtration and primary ozonation removed 99.34 percent of suspended solids, 74.01 percent of colour and 39.85 percent of CODcr, protecting downstream membranes. [S1001] Primary ultrafiltration removed 52.18 per-

cent of remaining turbidity and 17.34 percent of CODcr, yet had little effect on hardness, alkalinity, chloride, sulphate or conductivity. [S1001] Only across the reverse-osmosis membranes did conductivity fall by 92.94 percent in Stage 1 (two-year-old membranes) and 97.99 percent in Stage 2 (new membranes), with sulphate removals above 99 percent and chloride removals of 92.02 and 96.34 percent. [S1001] Ultrafiltration reduces suspended particles and macromolecular material but leaves nearly all dissolved salts and hardness in its permeate. Salt-sensitive reuse therefore needs additional desalination or softening. [S1001]

Second, cleaning streams follow different return paths. Primary and secondary sand-filter backwash of 1,500 cubic metres per day returned within Stage 1 after precipitation and re-filtration. Primary ultrafiltration backwash of 350 and primary reverse-osmosis wash of 130 cubic metres per day returned to the RO tank. Third-sand backwash of 750, secondary ultrafiltration backwash of 130 and secondary reverse-osmosis wash of 350 cubic metres per day returned to biochemical treatment, giving 3,210 cubic metres per day of internal cleaning flows rather than terminal losses. [S1001] Table 6 reports 6,098 kilograms per day of PAC and 234.65 kilograms per day of anti-scalant, reducing and sterilising agents. The nominal PAC dose on 75,000 cubic metres per day instead gives 6,000 kilograms per day, leaving an unreconciled 98-kilogram difference in the source's presentation. [S1001]

Third, membrane permeability and salt rejection depend on cleaning conditions. [S1001] [S1002] In Foshan, the economic model replaced ultrafiltration membranes every five years (1,224 elements) and reverse-osmosis membranes every three years (5,280 elements). [S1001] In a separate laboratory study at 60 percent recovery, permeability declined by more than 15 percent after 625 litres of permeate per square metre. The authors explicitly limit that cleaning threshold to the tested membrane, feed and operating conditions. [S1002] Combined acid and alkaline forward flushing restored specific flux to 87 percent of a new membrane. Adding pure-water backwashing at 0.125 megapascals and 0.5 metres per second restored 96 percent without measured rejection damage, whereas intensive backwashing at 0.5 megapascals and 1.5 metres per second degraded rejection. The preliminary chemical cost was 0.763 Chinese yuan per cubic metre of RO production, based on 750 litres per square metre before cleaning, not a universal full-cleaning cost. [S1002]

METHOD

To audit a candidate water-reuse train, GFT requires a closed daily mass, energy and chemical balance across the treatment boundary: 1. **Volumetric water conservation:** Verify that raw effluent feed (Q_{feed}) plus chemical make-up equals net permeate delivered to production ($Q_{\text{perm,1}} + Q_{\text{perm,2}}$) plus net unrecovered concentrate ($Q_{\text{conc,net}}$) plus water retained in dewatered sludge (Q_{sludge}) plus unreturned backwash or evaporative losses (Q_{loss}). Internal backwash loops (Q_{bw}) must be metered separately. [S04] [S1001] 2. **Dissolved solids conservation:** Track mass flow of total dissolved solids or conductivity ($Q \times C$) across each membrane stage ($Q_{\text{feed}} C_{\text{feed}} \approx Q_{\text{perm}} C_{\text{perm}} + Q_{\text{conc}} C_{\text{conc}}$) to expose membrane bypass, seal leakage or backwash dilution. [S1001] [S1002] 3. **Separate physical resource ledgers:** Record treatment electricity (E_{treat}, in kilowatt hours per cubic metre of net permeate), chemical reagents (M_{chem}) and dewatered sludge mass (M_{sludge}) in parallel physical accounts before applying local prices. State whether each mass intensity uses feed or permeate as its denominator. [S01] [S1001]

10.4

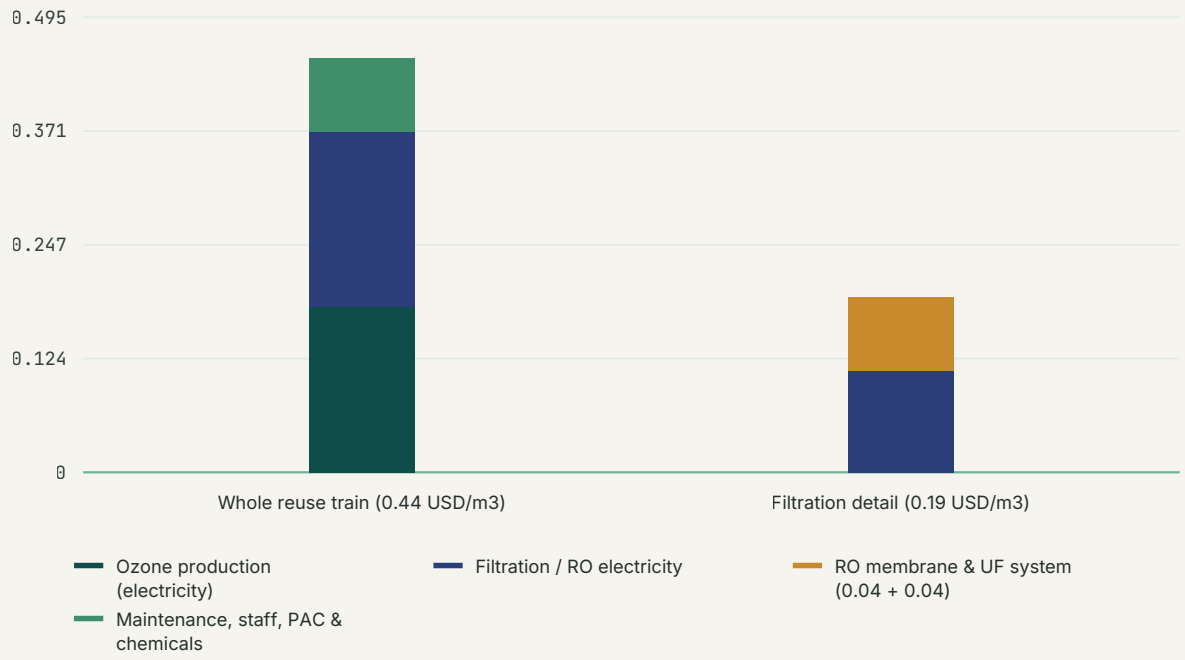
Reverse osmosis shifts part of the burden into energy and concentrate

High-recovery water reuse trades reduced freshwater intake for electrical power, chemical reagents, membrane consumables and a concentrated residual stream. [S06] [S1001] [S1003] Reporting only the reduction in cubic metres of water withdrawn conceals burden shifting across environmental categories. [S10] [S20] In GFT's accounting architecture, a reuse system is evaluated as an energy-consuming utility and a concentrate generator simultaneously. [S18] [S24]

The Foshan dataset quantifies the operating economics of advanced reuse. [S06] [S1001] Across 65,100 cubic metres per day of reclaimed water, reported operating cost was 0.44 US dollars per cubic metre at an electricity tariff of 0.10 US dollars per kilowatt hour. [S1001] Rounded components were 0.19 for sand filtration, ultrafiltration and reverse osmosis, 0.18 for ozone production, and 0.08 for maintenance, salaries, PAC and chemical agents. [S1001] RO pump electricity and membrane replacement were reported at 0.11 and 0.04 US dollars per cubic metre respectively, with ultrafiltration at 0.04. Electricity for ozonation and RO accounted for 64.84 percent of total operating cost (**Exhibit 46**, p. 164). [S06] [S1001]

EXHIBIT 46 / USD PER CUBIC METRE OF REUSE WATER

Treatment electricity dominates the Foshan reuse operating-cost account



SOURCED [S06] [S1001] One Foshan study at 0.10 USD/kWh. Rounded left categories sum to 0.45 USD/m3; reported total is 0.44, while detailed Table 6 inputs imply about 0.4413. Right components sum to 0.19. The separate 0.14 RO subtotal reflects rounding because 0.11 + 0.04 = 0.15. Post-biological train only, not a Cameroon forecast or ZLD cost.

Table 6 of the Foshan study shows the rising marginal energy penalty as recovery increases from 67.0 percent in Stage 1 to 86.8 percent across both stages. [S1001] Reclaiming 50,250 cubic metres per day in Stage 1 required 81,000 kilowatt hours per day for ozone and oxygen generation plus 60,288 kilowatt hours per day for pumps, totalling 141,288 kilowatt hours per day, or 2.81 kilowatt hours per cubic metre of primary permeate. [S1001] Reclaiming 14,850 cubic metres per day from primary concentrate required 35,046 kilowatt hours per day for ozone plus 21,384 kilowatt hours per day for pumps, totalling 56,430 kilowatt hours per day, or 3.80 kilowatt hours per cubic metre of secondary permeate. Secondary electricity intensity was about 35 percent higher. [S1001] The source separately reports total secondary unit operating cost as 0.086 US dollars per cubic metre higher than primary cost; that is not an electricity-only difference. [S1001] Combined treatment electricity reached 197,718 kilowatt hours per day, or 3.04 kilowatt hours per cubic metre. These figures cover the post-biological reuse train, not biological treatment, final brine disposal or ZLD. [S1001]

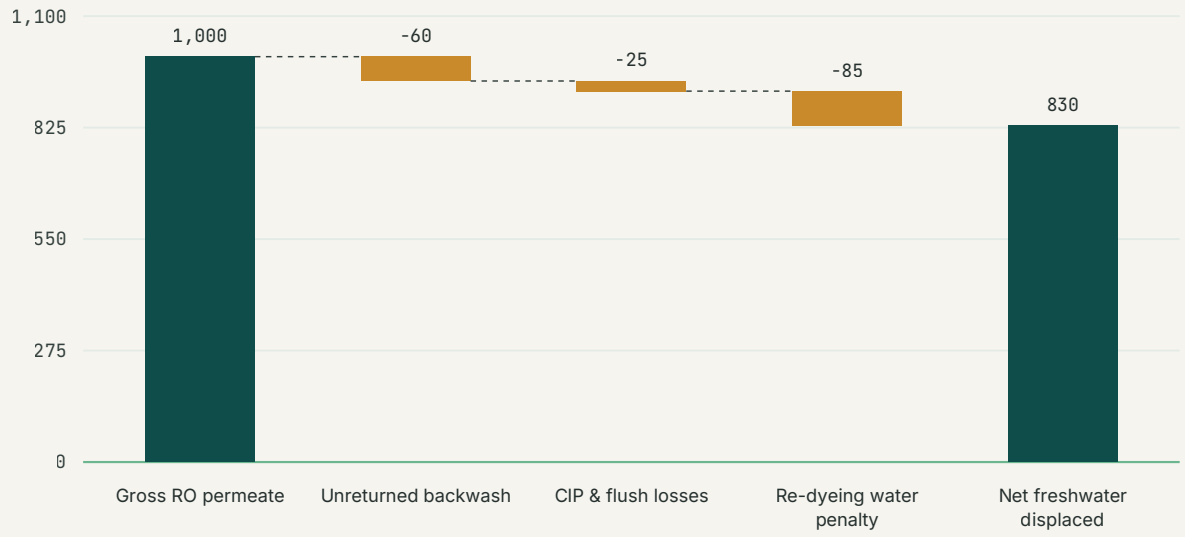
In Cameroon, power-sector reform is ongoing under a World Bank programme approved in August 2023, but neither grid reliability nor a low grid emissions factor can be assumed without site measurement. [S25] A train with electricity intensity near the Foshan value would add about 3 kilowatt hours per cubic metre of recycled water before final brine management. [S1001] Under ISO 50001 and GHG Protocol Scope 2 rules, electricity drawn by ozone generators and membrane pumps enters the fact-

ory's energy baseline and indirect emissions inventory. Captive diesel fallback during interruptions would also affect cost and emissions per accepted kilogram. [S16] [S18] [S19]

Equally critical is the fate of reverse-osmosis concentrate and chemical sludge. [S01] [S06] [S33] Reverse osmosis concentrates dissolved salts and refractory organics into the reject stream. [S06] [S1001] Without a salt purge or another outlet, recycled concentrate can increase loop salinity, inhibit biological treatment and raise osmotic pressure and required membrane feed pressure. [S06] [S1001] [S1003] Coagulation and biological treatment also generate 1 to 5 kilograms of dewatered sludge per cubic metre of treated wastewater. [S01] Internal recycling can reduce blue-water withdrawal, but pollutants remain in a smaller, more concentrated discharge or in solid waste unless they are destroyed or lawfully recovered. Recycling is not pollutant elimination. [S10] [S33] **Exhibit 47**, p. 165 and the worked example reconcile these flows in parallel physical ledgers. [S06] [S37] [S1001]

EXHIBIT 47 / ILLUSTRATIVE CUBIC METRES PER DAY (M3/D)

Gross permeate overstates net freshwater displaced when cleaning and re-dyeing are counted



ILLUSTRATIVE [S06] [S37] [S1001] Illustrative one-pass reconciliation. From 1,000 m3/d gross permeate, deduct 60 backwash, 25 cleaning losses and 85 additional re-dye demand, giving 830 m3/d net freshwater displaced. Cleaning flows are drawn from permeate; the re-dye penalty assumes 500 kg at 170 L/kg. Not a closed facility balance: re-dye effluent, dewatering filtrate, sludge moisture and evaporation need separate assignment. Other resources stay in parallel ledgers.

WORKED EXAMPLE: MULTI-LEDGER RECONCILIATION OF AN ILLUSTRATIVE DYEHOUSE REUSE LOOP

Consider an illustrative cotton reactive-dyeing facility sending 1,200 cubic metres per day of segregated effluent to a membrane train producing 1,000 cubic metres per day of gross reverse-osmosis permeate (83.3 percent apparent recovery). The comparable baseline uses 1,200 cubic metres per day of fresh water and has no additional hardness-excursion penalty. All figures are illustrative assumptions constructed to demonstrate GFT's accounting method, not measurements from a GFT or Cameroonian plant:

1. **Volumetric water ledger (cubic metres per day):** Assume 60 cubic metres per day of backwash and 25 cubic metres per day of clean-in-place (CIP) flushing are drawn from the 1,000 cubic metres per day of gross permeate and leave the treatment train. Net reusable supply is 915 cubic metres per day. RO concentrate of 200 plus cleaning residuals of 85 gives 285 cubic metres per day of treatment-train liquid residuals requiring a lawful outlet. Additional corrective re-dye demand of 85 cubic metres per day, equivalent to 500 kilograms at 170 litres per kilogram, reduces net freshwater displaced to $1,000 - 60 - 25 - 85 = 830\text{ m}^3/\text{d}$, or 69.2 percent of feed. [S37] [S1001] This is a one-pass treatment and demand reconciliation, not a closed facility balance: re-dye effluent, dewatering filtrate, sludge moisture and evaporation must be assigned separately.
2. **Accepted-output intensity (litres per accepted kilogram):** Assume the reuse case processes 10,000 kilograms per day, with 9,500 kilograms passing right first time and 500 kilograms re-dyed before release. [S37] The comparable baseline intensity is 120.0 litres per accepted kilogram. Net fresh intake with reuse is $1,200 - 830 = 370\text{ m}^3/\text{d}$, or 37.0 litres per accepted kilogram across 10,000 released kilograms. If the 500 kilograms were instead scrapped, a separate scenario, the denominator would be 9,500 kilograms and intensity would be 38.95 litres per accepted kilogram.
3. **Parallel electricity, chemical and sludge ledgers:** At an illustrative 3.0 kilowatt hours per cubic metre of gross permeate (patterned on 3.04 kilowatt hours per cubic metre in Foshan), the reuse plant uses $1,000 \times 3.0 = 3,000\text{ kWh/d}$, or 3.61 kilowatt hours per cubic metre of *net* freshwater displaced ($3,000 / 830$), plus rework steam and machine power. [S37] [S1001] At an illustrative 0.10 kilograms of chemicals and 2.0 kilograms of dewatered sludge per cubic metre of feed (within the IFC 1 to 5 kilograms per cubic metre range), the account records 120 kilograms per day of chemicals and 2,400 kilograms per day of sludge, kept in separate physical units until CFA franc (XAF) prices are applied. [S01] [S1001]

10.5

Sampling must represent production and treatment operation

A water-reuse and effluent-control system is only as credible as its sampling protocol. [S13] [S33] In a batch dyehouse, pollutant concentrations, temperature, pH and salinity vary as machines drain scouring baths, salty reactive dyebaths, soap-off washes or dilute rinses. [S01] [S02] A grab sample taken during a final rinse can make an inadequate plant appear compliant, while an uncalibrated inline conductivity probe can let a slug of hard permeate into the dyehouse header. [S33] [S1002] UN-Water's

2024 assessment of Sustainable Development Goal Indicator 6.3.1 warns that global estimation of total and industrial wastewater flows remains impossible due to widespread under-reporting, and emphasises that treatment figures require explicit disclosure of data coverage, flow basis and monitoring methods. [S13] At the factory level, GFT applies the same rule: no reuse quality figure or effluent concentration enters the batch ledger without its sampling method, flow-weighting basis, analytical standard and coverage period. [S13] [S33]

The ZDHC Wastewater Guidelines (Version 2.2) link sampling locations and parameter lists to chemical-input governance and discharge configuration. [S33] Full wastewater testing applies at or above an average industrial wastewater threshold of 15 cubic metres per day (annual industrial wastewater discharged divided by working days per year across wet processing, printing, laundry and washing). [S33] Qualifying facilities sample across two semi-annual cycles (October and April) across three locations depending on archetype: Untreated Wastewater (prior to any treatment), Discharged Wastewater (treated direct-discharge effluent or pretreated indirect effluent), and Sludge (residuals from primary, secondary and tertiary or zero-liquid-discharge operations). [S33]

Crucially, ZDHC requires Manufacturing Restricted Substances List (MRSL) parameters to be sampled and tested in *untreated* wastewater only. Listed heavy metals are tested in discharged effluent where applicable, but an indirect-discharge facility without pretreatment tests them in untreated wastewater because no treatment step exists. [S33] Testing untreated water checks for intentional use of restricted substances or input contamination before dilution, sludge sorption or oxidation can mask their presence. [S33] An MRSL non-conformity, including a sludge result above the applicable reporting limit, triggers Root Cause Analysis and a Corrective Action Plan directed at the chemical inventory and supplier Safety Data Sheets. [S32] [S33]

For conventional parameters and anions in direct-discharge facilities (Foundational, Progressive and Aspirational tiers), composite sampling must be paired with on-site hourly measurements for pH, temperature difference, persistent foam, flow rate, total chlorine and dissolved oxygen. [S33] While total suspended solids (textile limits of 50, 15 and 5 milligrams per litre) and total phosphorus (3, 0.5 and 0.1 milligrams per litre) carry numerical ceilings, ZDHC classifies total dissolved solids (TDS), chloride and sulphate as "Sample and Report only" parameters (SM 2540-C and ISO 10304-1 or ISO 15923-1). [S33] In a reuse loop, "Sample and Report" on TDS, chloride and sulphate is an operational red flag: because biological treatment does not remove chloride or sulphate, tracking their mass balance across untreated intake, permeate and concentrate is the primary check on salt accumulation and membrane integrity. [S06] [S33] [S1001]

Sludge sampling completes the mass balance, but ZDHC requirements depend on the disposal pathway. [S01] [S33] Pathways A to C have no testing requirement for pathway approval, although MRSL testing still supports input-chemistry corrective action. Pathways D and E require pH, percentage solids, paint-filter free liquids and cyanide tests; F and G add faecal coliform, with metals and leachate rules applied as specified. [S33] At 5 percent solids or less, dewatering or drying is expected before transport, except where local law permits safe transport of liquid sludge to an external agency for treatment or disposal without environmental impact. [S33] The site must record the

pathway, applicable tests and actual solids content rather than apply one test list to every load. IFC's separate benchmark of 1 to 5 kilograms of dewatered sludge per cubic metre provides a mass-accounting cross-check. [S01] [S33]

> **WARNING**
>
> Never accept a water-reuse pilot or compliance report based on unscheduled grab samples or permeate-only testing. Grab samples taken during low-load rinse cycles understate peak dyebath salt and colour loads, while testing permeate alone conceals what has accumulated in the membrane concentrate and clarifier sludge. Require flow-proportional composite sampling across a full representative shade cycle, simultaneous sampling of feed, permeate, concentrate and dewatered sludge (including percentage solids at 105 degrees Celsius), and timestamp alignment between laboratory certificates and dyehouse batch numbers. [S13] [S33] [S1001]

10.6

Zero liquid discharge is a site decision, not a default slogan

Zero liquid discharge (ZLD) is one boundary configuration among ZDHC's wastewater archetypes, and its merit depends on local hydrology, receiving-water conditions, energy supply and residual-solids management. [S02] [S33] [S1003] Under the ZDHC Wastewater Guidelines, ZLD means no industrial wastewater is discharged from the site in liquid form to the environment. Any such discharge, including recycled wastewater used for gardening or grounds irrigation, disqualifies ZLD status. [S33] ZDHC Table A requires ZLD facilities to test untreated wastewater for all MRSL parameters and to manage sludge and crystalliser residuals under the applicable disposal-pathway rules. [S33]

In Foshan, two reverse-osmosis stages recovered 86.8 percent of the 75,000 cubic metres per day inflow at 3.04 kilowatt hours and 0.44 US dollars per cubic metre. The simplified balance leaves 9,900 cubic metres per day (13.2 percent) unrecovered, derived by difference and returned to biochemical treatment in the documented configuration rather than proven as an environmental discharge. [S06] [S1001] The residual fraction in another system depends on its membranes and recycle configuration. Closing the liquid gap may require additional brine concentration, evaporation, crystallisation or another verified no-liquid-discharge arrangement. [S01] [S1003] Recovered salts and solids require characterisation and a lawful recovery or disposal pathway. Hazardous-waste containment applies only where composition, testing and local law require it, not merely because the solids came from a ZLD train. [S33] [S1003]

GFT therefore compares five design options before recommending a target recovery rate. This engineering menu is distinct from ZDHC's five discharge archetypes: [S01] [S02] [S33]

- **Direct discharge after compliant treatment:** Treated effluent is discharged to surface water with verified assimilative capacity after meeting local permits, IFC guideline values (pH 6 to 9, BOD 30 milligrams per litre, COD 160 milligrams per litre, TSS 50 milligrams per litre and AOX 1 milligram per litre) and ZDHC limits, paired with internal countercurrent rinsing and cooling-water reuse. [S01] [S33]

- **Indirect discharge with on-site pretreatment to a central effluent treatment plant (CETP):** High-load streams are pretreated on site (with or without sludge generation) before routing to a verified CETP, while clean streams cascade locally. [S01] [S33]
- **Targeted internal cascade without reverse osmosis:** Cooling water, condensate and clean preparation and bleach rinses are reused directly in upstream desizing, scouring and washing at minimal pumping energy and zero membrane-brine generation. [S01] [S02]
- **High-recovery membrane polishing for partial reuse:** Biologically treated effluent is polished through ultrafiltration, ozonation or activated carbon and reverse osmosis to supply permeate for suitable duties, while concentrate receives verified treatment and a lawful liquid outlet. [S06] [S1001] [S1002]
- **Full Zero Liquid Discharge (ZLD):** Membrane concentrate is routed to evaporation, crystallisation or another verified residual configuration so no industrial liquid is discharged to the environment. The option proceeds only after energy demand, emissions, reliability and a compliant solids pathway have been demonstrated for the site. [S01] [S33] [S1003]

> **GFT NOTE**
>
> Do not write an arbitrary reuse percentage or a blanket Zero Liquid Discharge slogan into a Cameroon tender specification before completing a catchment, grid and waste-pathway audit. Require the engineering study to model three options on the same accepted-output denominator: (1) source segregation plus countercurrent cascade, (2) membrane reuse with a compliant liquid concentrate outlet, and (3) membrane reuse followed by evaporative or equivalent residual management sufficient for ZLD. Two-stage RO alone is not ZLD. Approve higher recovery only when incremental freshwater saved justifies the measured increase in kilowatt hours, Scope 2 emissions, chemical dosing and solids-disposal risk. [S06] [S19] [S33]

Linking this circulation framework to GFT's digital spine would keep water reuse governed in daily operations. [S18] [S24] The recommended record for GFT's batch ledger and related tools gives every cubic metre of recycled water a batch-linked quality tag for conductivity, hardness, pH and colour at the reuse header. Daily kilowatt hours, chemicals, backwash volumes, concentrate outflow and dewatered-sludge mass are then reconciled against accepted kilograms of fabric or garments.

[S24] [S1001] When water quality is matched to the next duty and every residual stream stays inside the boundary, circulation becomes a verifiable engineering reduction rather than a displaced cost.

Recycled water is only as clean as the next dye bath requires, and only as sustainable as the energy and brine it leaves behind.

CHAPTER SOURCE NOTES

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S06 MDPI, Processes. 2019-01-11.

S02 European Commission Joint Research Centre. 2023.

S37 Emerald Publishing Limited. 2019.

S1001 MDPI, Processes (full-text repository at Living Archive for Process Systems Engineering). 2019-01-11.

R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.

R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.

S03 VTT Technical Research Centre of Finland, Telaketju. 2024-04-16.

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S38 European Commission. 2022-12-09.

S31 Springer Nature, Scientific Reports. 2022-12-26.

S24 Sustainable Apparel Coalition. 2022.

S18 International Organization for Standardization. 2018.

S1002 Multidisciplinary Digital Publishing Institute (MDPI), Membranes. 2026-01-04.

S36 Elsevier, Dyes and Pigments. 2024.

S04 PLOS Sustainability and Transformation. 2023-07-31.

S10 Earthscan, for Water Footprint Network. 2011.

S20 International Organization for Standardization. 2006.

S25 World Bank. 2025-06-25.

S16 MDPI, Energies. 2022-11-25.

S19 GHG Protocol. 2015.

S33 ZDHC Foundation. 2024.

S13 UN-Habitat and World Health Organization, for UN-Water. 2024.

S32 ZDHC Foundation. 2023.

GREEN FUTURE TECH

LIMITED / HONG KONG SAR

11

PART III: REDUCTION IS A SYSTEM / THE THERMAL SYSTEM

Heat recovery begins with temperatures and timing, not equipment

A recovery or electrification project earns its place only when a measured source can serve a measured sink at the required time, temperature and emissions factor.

CHAPTER 11
DECISION TEST

A recovery or electrification project earns its place only when a measured source can serve a measured sink at the required time, temperature and emissions factor.

Heat recovery should be selected from a timed map of sources and demands, then tested against the heat actually delivered to accepted production. A hot stream alone does not establish an opportunity. The receiving duty must accept its temperature, flow, availability and contamination controls. GFT recommends reducing avoidable demand, pairing compatible streams, and only then selecting exchangers, storage, heat pumps or replacement supply. This chapter provides a proposed engineering decision method, not a record of installations or achieved GFT savings. Its starting principle follows the Department of Energy's systems approach, which examines interactions before individual equipment. [S17]

11.1

The source-and-sink register comes before technology selection

The Department of Energy recommends mapping material and energy movements before prioritising component improvements. Its industrial waste-heat tables describe broad source classes, rather than measured conditions at a textile factory. They are useful prompts for investigation, but neither prove that a particular stream exists nor establish recoverable power. [S17] GFT's proposed register should therefore attach an evidence status to each stream: measured, estimated, supplier-declared or unavailable. An engineering team should be able to trace every candidate match back to the observations that justify it.

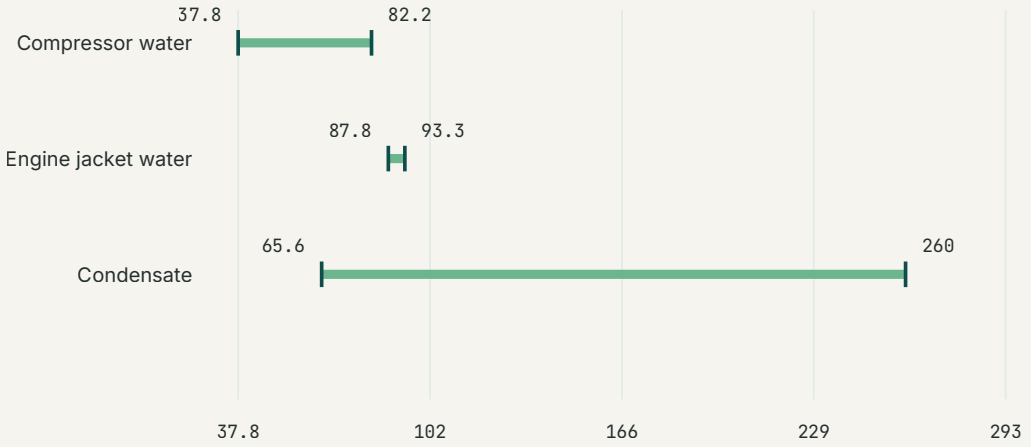
For a source, record its identity, physical medium, mass flow, inlet temperature, permissible outlet temperature and operating window. Add batch identity, solids, corrosive constituents, pressure, location and access for cleaning. For a sink, record incoming conditions, required delivery temperature, acceptable temperature variation, demand profile and production consequences if delivery fails. These are proposed design fields. A source described merely as hot wastewater and a sink described merely as hot water cannot support procurement, because neither entry defines what heat can cross the boundary.

The register should separate sensible heat from phase-change duties. A liquid cooling without boiling can be screened through mass flow, heat capacity and temperature change. Steam and condensing vapours require an enthalpy balance at the relevant pressure. GFT recommends documenting the property basis and whether a reading represents bulk fluid, a pipe surface or an inferred temperature. Those distinctions should remain visible when the preliminary register becomes a supplier specification. A convenient sensor location should not silently redefine the thermal boundary.

For preliminary screening, **Exhibit 48**, p. 173 converts selected published industrial ranges into Celsius. The selection deliberately includes utility streams that could be investigated around an industrial site. It is not a textile-process temperature specification. The conversion is arithmetic from the Department of Energy table, and the ranges retain its broad scope. [S17]

EXHIBIT 48 / DEGREES CELSIUS

Published source ranges prompt measurement, not recovery promises



DERIVED [S17] DOE Third Edition, Table 5: compressor cooling water 100 to 180 F; engine jacket water 190 to 200 F; condensate 150 to 500 F. Conversion C=(F-32)*5/9, rounded to one decimal. General industrial categories, not measurements at a textile plant. Temperature does not establish available duty or permissible cooling.

A high temperature range should not automatically win the ranking. GFT proposes ranking compatible matches by the useful duty available during production, after access, cleanliness and control constraints. A nearby moderate-temperature source may serve water preheating directly, while a distant hotter source may require pipework and operating arrangements that defeat its apparent advantage. This is a proposed selection rule, not a quantified comparison. The technical team should preserve the reason for rejecting a match so later equipment proposals do not revive an already disproved assumption.

Timing requires a shared clock. GFT recommends logging source discharge and sink filling against the same batch events, including cleaning, idle periods and recipe changes. An illustrative source delivering heat during a drain event cannot be paired automatically with a machine that filled before that event. The analyst should compare overlap intervals, not multiply unrelated annual totals. Where a buffer is proposed, its usable temperature range, losses and dispatch rule become explicit assumptions. Storage can shift delivery within its design envelope; it cannot create a missing thermal source.

GFT recommends carrying uncertainty through the screening calculation. A temperature difference calculated from instruments with uncertain offsets may have a much larger relative uncertainty than either temperature reading suggests. Flow, heat-capacity assumptions and incomplete event capture should each receive a stated basis. The reviewer should identify which uncertainty could reverse the choice between candidates, then commission that measurement first. A longer list of precise-looking outputs is less useful than resolving the input that determines whether a match works. The register should preserve missing intervals and rejected readings, together with the rule for excluding them. An inferred stream should remain an estimate until a suitable measurement replaces it; its apparent precision should not change because it appears in a chart.

GFT NOTE

Commission a source-and-sink register before requesting equipment quotations. Require every proposed match to state the receiving duty, temperature approach, simultaneous availability, contamination barrier, maintenance access and fallback route. Keep unverified streams outside the committed savings case. The register should remain usable by production and utilities staff, rather than existing only in the supplier's calculation file.

11.2

Boiler losses offer measured, not assumed, opportunities

The Department of Energy's economiser tip sheet reports that fuel requirements can often fall by 5 to 10 percent, with payback below two years. It also requires assessment after boiler tuning, with clean heat-transfer surfaces and appropriate excess air, and warns that cooling limits depend on corrosion and condensation conditions. These are screening statements in a dated guide, not a Cameroon quotation, a warranty or a GFT result. [S27]

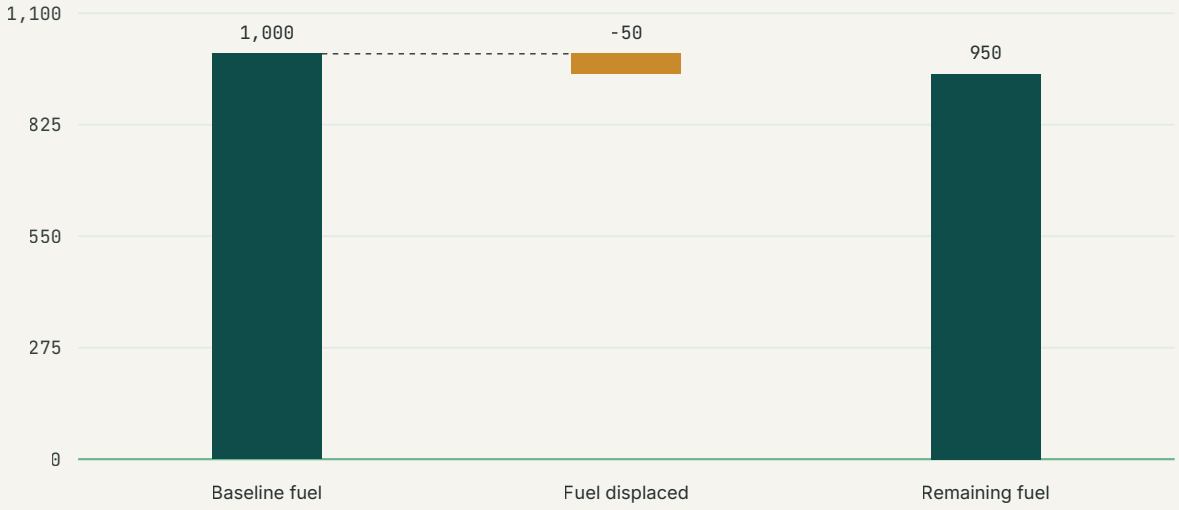
GFT recommends separating restoration of the existing boiler from incremental recovery. Record operating load, fuel basis, feedwater condition, steam pressure, flue-gas temperature and combustion settings before and after routine corrective work. If the baseline includes avoidable malfunction and the project includes its repair, the resulting improvement should be attributed transparently. An economiser should not receive credit for tuning that would have happened anyway. Conversely, the project should not be evaluated against a nominal catalogue efficiency when the operating boiler behaves differently.

The proposed review should extend beyond the stack. Utilities staff should inspect steam leaks, insulation condition, condensate collection, return temperature and operating schedules, then identify which actions alter the economiser's receiving duty. GFT's purpose is to prevent separate teams from claiming the same heat. For example, a proposed condensate-return improvement should update the feedwater conditions used in the economiser model. Equipment sizing should follow the revised balance. This is a coordination requirement for the engineering study, rather than a claim about a measured plant.

The fuel bridge in **Exhibit 49**, p. 175 is an illustrative annual account. It shows only boiler fuel, so an auxiliary electricity penalty cannot disappear inside a mixed-energy total. Every value is an assumed modelling input or arithmetic from those inputs. The separate worked example explains the boundary and makes the illustration reproducible.

EXHIBIT 49 / ILLUSTRATIVE MWH OF FUEL PER YEAR

Recovered heat reduces the fuel needed for an unchanged duty



ILLUSTRATIVE Assume baseline fuel 1000 MWh/year, useful duty 800 MWh/year and constant marginal boiler efficiency 0.80. Assume recovery of 10 kW for 4000 coincident hours, giving 40 MWh useful heat. Displaced fuel=40/0.80=50 MWh; remaining fuel=(800-40)/0.80=950 MWh. Pump electricity 4 MWh/year is a separate ledger item, not a fuel deduction. No measured GFT performance is represented.

AN ILLUSTRATIVE ECONOMISER ACCOUNT PRESERVES THE USEFUL DUTY

In this illustrative case, assume an existing boiler uses 1,000 MWh of fuel annually and delivers 800 MWh of useful heat, with marginal efficiency held at 0.80 solely for this illustration. Assume an added exchanger supplies 10 kW of useful preheat over 4,000 coincident hours. Recovery is 10 multiplied by 4,000 divided by 1,000, or 40 MWh annually. The remaining boiler duty is 760 MWh, requiring 760 divided by 0.80, or 950 MWh of fuel. The modelled fuel reduction is therefore 50 MWh, or 5 percent. That numerical agreement with a published screening range does not validate any of the assumed inputs.

Assume additionally that circulation consumes 4 MWh of electricity annually. The illustrative report must then show fuel falling by 50 MWh and electricity rising by 4 MWh, with unchanged accepted output and useful duty. Net purchased final energy falls by 46 MWh under these assumptions. Cost and emissions require separate fuel and electricity factors. No payback follows until capital cost, operating cost and persistence have been established; no currency conversion or tariff is assumed here.

The illustration holds efficiency constant to expose the calculation. GFT recommends replacing that assumption with a load-dependent assessment before approval. Recovered preheat can change burner operation, so a trial should include conditions where the boiler operates lightly as well as conditions where demand is high. The sign-off should explain whether measured fuel reductions came from recovery, changed output, altered operating hours or other interventions. Heat delivered by an exchanger is evidence of transfer; fuel reduction under comparable conditions is evidence of displacement.

Commissioning should include an explicit counterfactual. GFT recommends agreeing what the existing plant would consume at the same useful duty, product mix and operating state without recovery. Where a controlled bypass comparison is feasible, the trial plan should define how to avoid confusing transient reheating with steady operation. Where it is infeasible, explain the model and its uncertainty. Keep control changes and maintenance interventions in the event log, including those that are unrelated to the new equipment. The owner should be able to reproduce the reported displacement from retained readings and assumptions. This proposed verification contract should be agreed before installation, because a baseline cannot always be reconstructed after the flow arrangement has changed.

For verification, GFT proposes recording exchanger inlet and outlet conditions alongside fuel use, boiler load, availability and accepted output. The comparison should include cleaning and bypass periods. Where direct fuel attribution is uncertain, report the heat-transfer measurement and the modelled displacement separately. A model should not be promoted to measured saving merely because an instrument appears on the drawing. The investment assessment elsewhere in this paper can then value a technically qualified saving without having to reconstruct its boundary.

11.3

Warm effluent is both a heat source and a process constraint

IFC's textile guidance explicitly recommends recovering heat from continuous dyeing or bleaching and from hot batch effluents to preheat incoming water. It also connects water use with wastewater, sludge and heating demand. These recommendations support examining the water and thermal systems together; they do not establish a universal recovery fraction. [S01] GFT recommends distinguishing heat exchange across a barrier from direct reuse of the liquid. A scheme may recover heat while keeping contaminated liquid entirely outside the receiving process.

The proposed stream review should preserve recipe identity through the drain event. Combine streams only after establishing that mixing is necessary and compatible with the intended recovery route. The study should ask whether segregation preserves a higher-temperature source, simplifies cleaning or protects a downstream treatment requirement. It should also ask whether the proposed segregation is operable during production. A theoretical match that requires staff to recognise an unmarked pipe or change valves without a clear instruction should remain a design problem, not an assumed operating benefit.

GFT recommends specifying a contamination barrier and a response to barrier failure. The design review should identify which side contains process water, which side supplies the receiving duty, where leakage would travel and how the failure would be detected. Pressure arrangements, isolation and suitable inspection provisions belong in the engineering specification. This chapter does not prescribe an exchanger construction or approve a sanitary design. Its recommendation is that the receiving process must have a defined protection argument before recovered heat is credited.

Fouling should be treated as a changing operating condition, rather than a constant correction attached to a clean calculation. GFT proposes recording delivered duty, approach temperatures, pressure drop and cleaning events together. The maintenance plan should explain how the exchanger is isolated, drained and returned to service, and where cleaning residues go. The acceptance trial should include the condition near the planned cleaning point. Otherwise, a brief test could demonstrate what freshly cleaned equipment can transfer while leaving sustained production performance unresolved.

AN ILLUSTRATIVE EFFLUENT MATCH SHOWS WHY THE RECEIVING DUTY MATTERS

Assume a water-like effluent stream of 5,000 kg per hour cools from 60 to 40 degrees Celsius. Assume heat capacity of 4.18 kJ per kg per kelvin, used here as an illustrative constant for dilute water. Available sensible duty is 5,000 multiplied by 4.18 multiplied by 20 divided by 3,600, or approximately 116.1 kW. These assumptions do not describe an analysed effluent, a guaranteed exchanger duty or a safe treatment temperature.

Assume the receiving stream is also 5,000 kg per hour and must rise from 25 to 40 degrees Celsius. Its illustrative demand is approximately 87.1 kW. With sufficient exchanger area and compatible approach temperatures, that receiving duty sets the screening ceiling, rather than the larger source figure. During an assumed three-hour overlap, the ceiling is about 261.3 kWh. If the streams do not overlap and no qualified storage exists, direct recovery during that interval is zero. A design calculation must still check heat transfer, fouling, pumping and operational constraints.

GFT recommends a treatment review before fixing the source outlet target. The treatment operator should define permissible inlet conditions and how they will be monitored during the pilot. Recovery must also preserve the established discharge and production controls. A lower discharge temperature should not be claimed as permission to change any other parameter. The handover should specify a safe bypass route and what happens to production if the recovery equipment fails. Heat recovery should add a controlled option, rather than make wastewater handling dependent on an unproved device.

The recovery layout should also survive ordinary production changes. GFT recommends walking through shade changes, machine cleaning, unplanned stoppage and a receiving tank already at its permitted temperature. Each state needs a destination for the source stream and a clear indication of whether recovery is active. A control system should not retain an assumed demand after that demand has ended. The pilot record should show heat rejected during these states rather than deleting the states from the annual denominator. This gives the scheduler a realistic account of recoverable duty and prevents an operating instruction from asking staff to create unnecessary hot-water demand merely to maintain a favourable recovery ratio.

The proposed ledger should enter freshwater volume, effluent volume and thermal exchange as distinct quantities. An exchanger that preheats incoming water has not necessarily reduced water withdrawal. The heat removed from the effluent and the heat delivered to the incoming stream are opposite sides of the same transfer, not

additive savings. GFT recommends assigning the transfer a common identifier, reconciling discrepancies and reporting auxiliaries separately. This prevents the reuse and energy teams from counting the same benefit in incompatible accounts.

11.4

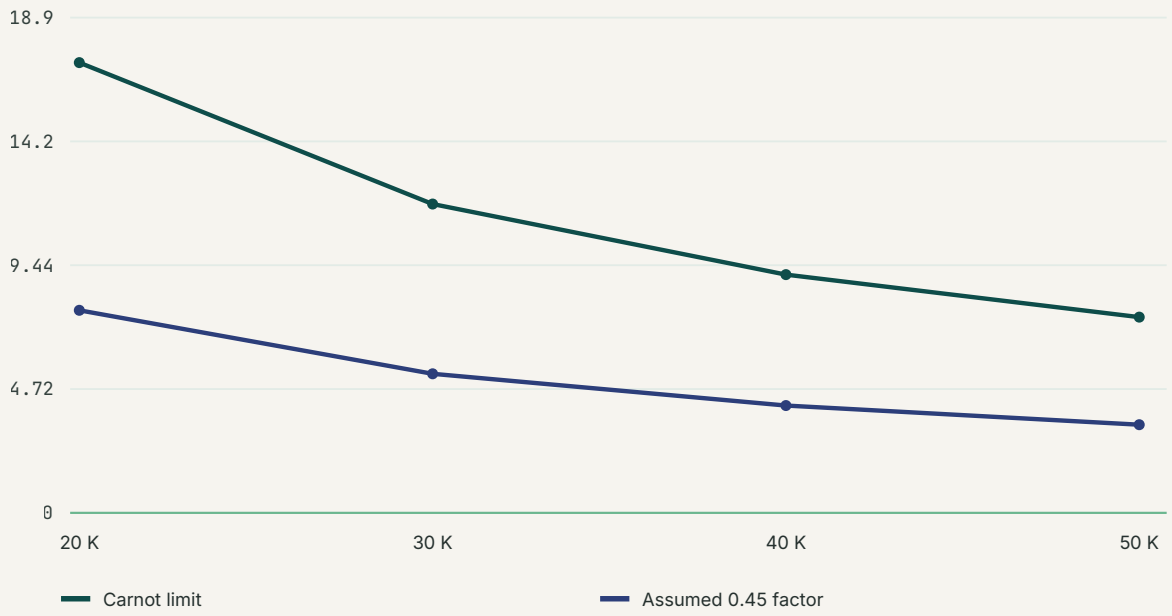
Heat pumps move heat with a site-specific coefficient

The textile electrification study defines heating coefficient of performance as useful thermal output divided by external energy input. Its theoretical treatment relates performance to source and sink temperatures and qualifies integration as plant-specific, requiring pinch analysis for an optimum arrangement. [S1101] The practical consequence is a proposed selection sequence: use direct compatible transfer where justified, identify the residual temperature requirement, then investigate whether a heat pump can serve it. A source suitable for direct preheating should not automatically be assigned to powered upgrading.

The conceptual curve in **Exhibit 50**, p. 178 uses the article's thermodynamic relationship with invented operating temperatures. Absolute temperature enters the ratio. The second curve is an assumed fraction of the theoretical limit, chosen only to demonstrate sensitivity. It is not a real-machine performance curve, a product comparison or a sizing basis. External heat-exchanger approaches and system auxiliaries would need their own treatment before a supplier performance guarantee could be assessed. [S1101]

EXHIBIT 50 / ILLUSTRATIVE HEATING COP, THERMAL KWH PER ELECTRICAL KWH

A greater temperature lift lowers the illustrative heating COP



ILLUSTRATIVE [S1101] Article heating-mode Carnot relationship: COP=T_sink/(T_sink-T_source), temperatures in kelvin. Assume reservoir source 50 C (323.15 K) and sinks 70,80,90,100 C. Horizontal labels show temperature lift in kelvin. Second curve assumes 0.45 times Carnot solely for sensitivity; it is not measured real COP and excludes auxiliaries. Values rounded to two decimals.

For procurement, GFT recommends defining performance at the receiving process boundary. The specification should state which electrical loads are included, which temperatures are guaranteed, what source flow is available and which operating states are excluded. A compressor-only ratio and a system ratio should have different labels. Useful heat should be measured where it serves the production duty, while the electrical account should include the declared system boundary. The supplier should provide the test method and the conditions under which the guarantee ceases to apply.

GFT proposes calculating a period coefficient from total useful heat divided by total system electricity over that same period. Do not average isolated operating ratios without considering their energy weights. The record should include standby electricity, source interruptions, cycling and cleaning whenever those states are inside the declared boundary. An unavailable source cannot remain a full-capacity input in an annual model. An apparent gain caused by excluding difficult periods should be reported as a boundary change, not improved equipment performance.

Source allocation also needs conservation. In an illustrative heat pump delivering 300 kW at a heating COP of 3, compressor electricity is 100 kW and extracted source heat is 200 kW, ignoring other losses and auxiliaries for the example. A direct-recovery scheme cannot simultaneously consume that same source heat in a separate fully additive saving. GFT recommends drawing the residual source profile after each proposed intervention. This is especially important when direct exchange, recovery storage and heat pumping are offered as independent projects by different suppliers.

A supplier comparison should use an agreed operating envelope rather than a single favourable point. GFT recommends asking bidders to declare performance across the measured source and sink conditions, including the lowest expected source availability and the required final delivery temperature. Record restrictions on turndown, refrigerant handling, maintenance competence and service response as procurement inputs. These fields are proposed requirements, not claims that any selected supplier can meet them. A bid with a strong nominal coefficient but an unresolved integration duty should remain technically incomplete. The evaluation should retain the original response and the accepted assumptions so later design changes can trigger a deliberate reassessment rather than silently inheriting an obsolete performance claim.

The trial plan should test the proposed control hierarchy. GFT recommends documenting when direct transfer takes priority, when the heat pump starts, how a buffer is charged and how the existing heat supply fills any shortfall. The production operator should receive a simple indication of whether the required temperature has been achieved. Thermal optimisation should not create an incentive to accept a non-conforming process condition. A pilot passes only when the equipment and the operating instruction work together under the site's intended product and schedule variation.

11.5

Electrification must pass an emissions and capacity test

The textile electrification study shows that lower final energy does not invariably produce an immediate emissions reduction when grid electricity is carbon intensive. Its scenarios concern specified Asian economies and are not forecasts for Cameroon. [S1101] GHG Protocol treats purchased electricity, steam, heat and cooling within its purchased-energy accounting guidance. Its published guidance also addresses contractual instruments. [S19] GFT therefore recommends showing the physical energy comparison separately from the inventory method, with the reporting period and factor basis visible.

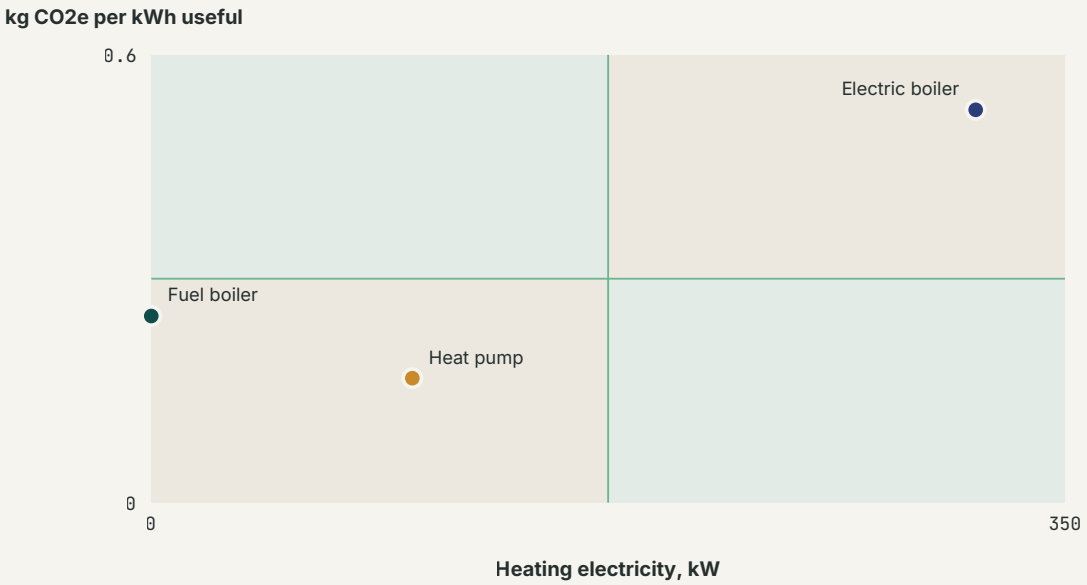
A proposed screening calculation compares emissions for the same useful duty. Let the fuel factor apply per unit of fuel input, boiler efficiency convert fuel to useful heat, and the electricity factor apply per unit of purchased electricity. A heat pump's operating emissions per useful thermal unit then equal the electricity factor divided by system COP. Boiler operating emissions equal the fuel factor divided by efficiency. This is a simplified GFT comparison method. It excludes upstream, refrigerant and embodied burdens unless they are explicitly added with consistent evidence.

The emissions threshold follows from that boundary. Heat pumping has lower modelled operating emissions when the electricity factor is below COP multiplied by the fuel factor divided by boiler efficiency. For a direct electric boiler, substitute its delivered-heat efficiency for COP. A good technical ratio does not supply an electricity factor. GFT recommends retaining an unresolved result where current site electricity evidence is missing, rather than inserting a convenient national or regional value. The same discipline applies to a fuel factor whose calorific-value basis has not been established.

The matrix in **Exhibit 51**, p. 181 applies invented factors to an equal useful duty. Its coordinates are calculated quantities, not qualitative attractiveness scores. It shows why electrical capacity and emissions should be assessed independently. The combustion point excludes auxiliaries solely to keep the illustrative boundary explicit; an actual comparison must include them consistently.

EXHIBIT 51 / ILLUSTRATIVE OPERATING COMPARISON AT 300 KW USEFUL HEAT

Equal useful heat can require different power and emissions



ILLUSTRATIVE Assume fuel factor 0.20 kg CO2e/kWh fuel and electricity factor 0.50 kg CO2e/kWh electricity. These are invented sensitivity inputs, not Cameroon factors. Boiler efficiency 0.80 gives fuel 375 kW and emissions 0.25 kg/kWh useful; electric boiler efficiency 0.95 gives power 315.79 kW and emissions 0.5263; heat-pump COP 3 gives power 100 kW and emissions 0.1667. Auxiliaries, upstream burdens, refrigerants and embodied impacts excluded throughout. X-axis measures incremental heating electricity only, not whole-site load.

In this illustrative case, the heat-pump threshold is 3 multiplied by 0.20 divided by 0.80, or 0.75 kg CO2e per kWh of electricity. The direct electric boiler threshold is 0.95 multiplied by 0.20 divided by 0.80, or 0.2375. The assumed electricity factor of 0.50 lies between them, so the model gives opposite emissions verdicts for the electrical options. Neither threshold is a Cameroon benchmark. The example demonstrates a decision rule whose result changes when its assumed factors change.

Capacity requires a different evidence packet. GFT recommends obtaining the site's measured coincident peak, connection limits, transformer assessment, protection review and proposed starting behaviour before assigning additional heating demand. The equipment nameplate alone does not establish electrical headroom. The operator should test recovery after interruption, because restarting production and reheating process fluids may coincide. Where backup supply is proposed, its actual capability and operating emissions must enter the same comparison. A design should preserve safe shutdown and process control even when heat delivery cannot continue.

11.6

Renewable supply follows efficiency and reliability design

The IEA's renewable-heat account published in 2022 attributes 53 percent of final energy consumed for heat to industrial processes. This is global context from that edition, not a current Cameroon mix or a textile-site share. [S26] GFT recommends using it to recognise the importance of the thermal boundary, then returning to the

measured site duty. Supply should be sized after avoidable demand and qualified recovery are accounted for. Otherwise, capacity and cost could be assigned to a load that the process redesign subsequently removes.

For Cameroon, the World Bank's report dated 25 June 2025 records the power-sector reform programme and its implementation status. [S25] That programme is evidence of sector activity. It does not establish this factory's connection capacity, interruption history or electricity emissions factor. GFT recommends obtaining those inputs from site observations and appropriate current records. Neither a national generation project nor a reform objective should be used as a substitute for the operating evidence needed to electrify a specific production duty.

The proposed supply comparison should retain the time profile of the residual heat load. For solar electricity, test how generation coincides with the electrical heating duty, other factory loads and planned operating hours. For solar thermal supply, test the receiving temperature and useful heat delivered through the proposed circuit. Storage should be assessed using its actual delivery boundary and usable operating range. GFT recommends keeping these pathways separate until they have been converted into comparable useful duty, availability, cost and emissions accounts.

A buffer should be specified by the service it must provide. GFT proposes defining the protected process, required delivery condition, duration, allowable interruption and recharge opportunity before selecting a storage medium. The study should account for standing loss, circulation electricity and temperature limits. If storage is needed only to align a batch drain with the next fill, that is a different service from maintaining heat through an extended supply interruption. Combining those requirements in one unexplained capacity figure makes the engineering decision difficult to inspect.

Renewable electricity procurement and physical reliability should also receive separate decisions. GFT recommends checking the inventory treatment and documentary quality of any contractual instrument under the applicable guidance, while independently testing how the plant receives power during production. [S19] A documentary emissions attribute does not demonstrate that a machine can complete its cycle during an interruption. Conversely, a reliable connection does not establish a low-carbon factor. The project brief should name both questions and record the evidence that closes each one.

For any proposed fuel substitution, GFT recommends specifying fuel quality, supply continuity, storage, emissions controls and operator competence before assuming availability. Residue-based options should have their own material account and competing-use assessment. The study should avoid treating a renewable label as sufficient evidence of low whole-system burden. This is a proposed diligence requirement, not a statement that any such fuel is available to GFT's programme. Site-specific environmental requirements and detailed plant design remain work for the responsible specialists.

GFT recommends a failure drill before routine operation. The team should simulate a source interruption, unavailable storage, recovery equipment isolation and a loss of the preferred power supply using an approved safe test method. Record which loads stop, which controls remain powered and how a batch is recovered or rejected. The purpose is to verify the operating response, not to demonstrate endurance beyond the

design envelope. Any extra reheating, reprocessing or disposal caused by the drill should remain identifiable in the trial account. A recovery project that works only when every connected utility is available has a conditional operating envelope; the handover should state that condition plainly rather than treating it as an exceptional footnote.

The thermal handover should leave a ranked set of qualified matches, rejected alternatives with reasons, measured operating envelopes and unresolved inputs. GFT recommends assigning each accepted match a production owner and a utilities owner, with a defined fallback, cleaning instruction and verification boundary. The resulting packet should feed the solar-storage and footprint tools with labelled inputs rather than prefilled benefits. Detailed valuation belongs in the investment chapter; the present chapter supplies the technical conditions that a credible valuation must preserve.

The recommendation is therefore operational: capture temperatures and timing, reduce the residual demand, prove transfer and displacement separately, then compare supply options at the same receiving boundary. Report absolute energy and energy per accepted output together, retaining quality and treatment constraints. If the evidence supports only a screening case, call it a screening case. This chapter is an engineering decision framework, not investment, legal or tax advice, and it provides no assurance of site performance or return.

Heat becomes a saving only when a useful duty receives it.

CHAPTER SOURCE NOTES

S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.

S27 United States Department of Energy, Advanced Manufacturing Office. 2012.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S1101 MDPI, Energies (author article accessed through PSE Community repository). 2022-11-25.

S19 GHG Protocol. 2015.

S26 International Energy Agency. 2022-12-06.

S25 World Bank. 2025-06-25.

GREEN FUTURE TECH

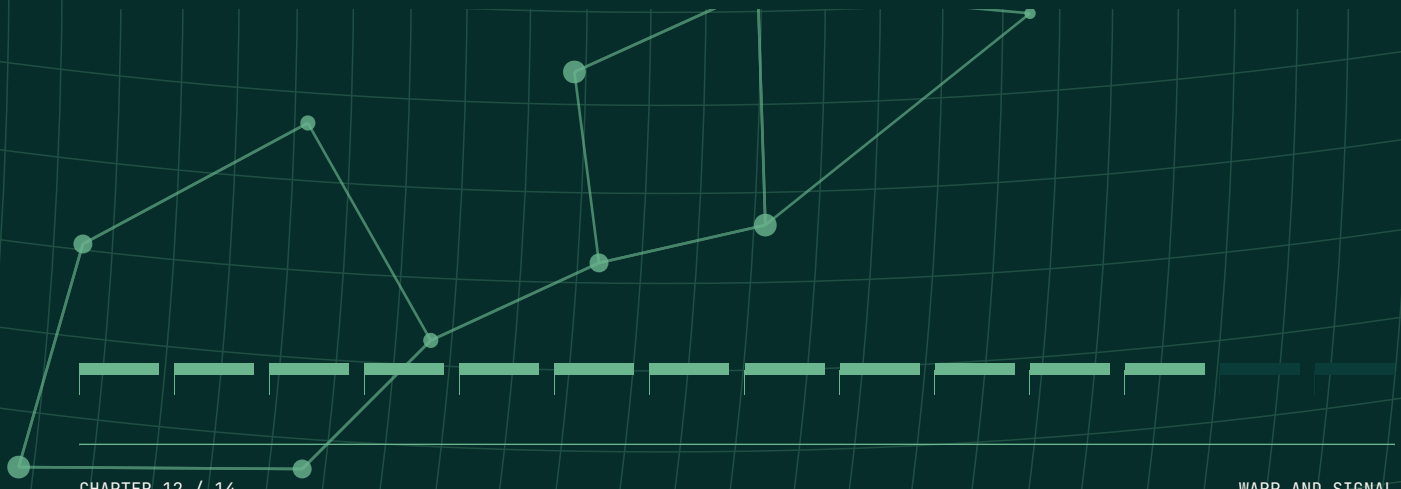
LIMITED / HONG KONG SAR

12

PART III: REDUCTION IS A SYSTEM / ECONOMICS AND PROOF

Investment should follow verified savings per accepted unit

A resource project is ready for capital only when its baseline, production effect and whole-cycle savings are measured with enough confidence to survive operating variance.



CHAPTER 12
DECISION TEST

A resource project is ready for capital only when its baseline, production effect and whole-cycle savings are measured with enough confidence to survive operating variance.

Capital for water, chemical and energy upgrades in a textile or garment plant should be released only after a reconciled baseline and paired operating trials prove that resource use falls per accepted unit without degrading colour, fastness, throughput or effluent quality. [S18] [S37] A supplier brochure or generic benchmark can nominate a technology for screening, yet neither establishes an investable cash flow for a specific mill. [S1202] Because saved water and saved energy represent the absence of consumption, they cannot be read directly from a single utility bill; they must be calculated by comparing metered use before and after the intervention while adjusting for volume, product mix, shade depth and operating hours. [S29] [S1201] In Green Future Tech Limited's (GFT) Cameroon textile programme, prepared in January 2024 with source-refresh notes retained in 2026, local industrialisation is framed around moving raw cotton processing from an approximate 5 percent domestic baseline toward the 50 percent national target for 2030. [R06] [R07] Mobilising capital inside that expansion requires an engineering valuation discipline that prices the internal cost of water, steam, power, chemicals, treatment and rework, tests payback ranges against Cameroon's operating risks, and gates procurement behind measured proof. This chapter sets out that engineering and management method; it is not investment, legal or tax advice, and it does not forecast returns for any facility.

12.1

The baseline is a financial control as well as a technical one

An unverified resource baseline is an open-ended financial liability because any error in the starting denominator or boundary transfers directly into the claimed return on capital. [S18] [S1201] When a factory board evaluates a low-liquor dyeing retrofit, a countercurrent washing train, a wastewater reverse-osmosis unit or a boiler economizer, the baseline defines the counterfactual trajectory against which future cost reductions are judged. [S01] [S27] [S1201] Under ISO 50001:2018, an energy management system requires documented energy performance indicators and baselines that retain the variables affecting consumption. [S18] Empirical benchmarking of textile manufacturing confirms that specific energy consumption (SEC), defined as energy used per unit of output, fluctuates with monthly production volume, capacity utilisation and seasonal heating demand. [S29] Treating a single utility bill or an unadjusted annual ratio as a financial baseline confuses workload variation with engineering improvement. [S29] [S1201]

12.2 ABSENCE OF CONSUMPTION CANNOT BE READ FROM A SINGLE UTILITY METER

Measurement and verification (M&V) engineering starts from a foundational constraint: energy and water savings cannot be measured directly by a single instrument because savings represent the absence of resource use after an intervention is installed. [S1201] Verified savings must be calculated by comparing metered resource use before and after the measure while adjusting for independent variables that govern demand, including accepted fabric mass or garment count, fibre blend, construction, shade depth, batch size, intake water temperature and shift utilisation. [S02] [S29] [S1201]

A three-year study of a Latvian textile producer across ten product categories shows why raw monthly ratios fail as financial controls. [S29] Linear regression of specific electricity consumption against monthly production volume yielded a coefficient of determination (R2) of 0.6404, confirming an inverse relationship in which unit electricity demand fell as volume rose because fixed equipment and downtime loads were spread over more fabric. [S29] Specific natural gas consumption showed winter seasonality and a weak linear correlation with volume (R2 = 0.1835), while accounting output solely in thousands of metres without separating fabric mass and product category distorted performance tracking. [S29] Commissioning a project during a shift from low-volume winter runs to high-volume summer runs would falsely credit the vendor for reductions generated by higher line loading and warmer intake water. [S29] [S1201]

12.3 BASELINE SIGN-OFF LOCKS BOUNDARY, PRODUCT MIX AND MEASUREMENT UNCERTAINTY

To serve as an audit control, the baseline record must be signed off by engineering, production and finance before any trial or procurement begins. [S18] [S1201] First, the sign-off defines the boundary under retrofit isolation (tracking the dye machine, stenter or compressor loop) or whole-facility metering. [S24] [S1201] The United States Department of Energy's Federal Energy Management Program (FEMP) M&V Guidelines classify retrofit isolation into Option A, which measures key parameters while estimating secondary factors, and Option B, which meters all parameters governing the measure. [S1201] For textile retrofits where liquor ratio, rinse flow, steam and rework interact, GFT requires Option B submetering reconciled against the utility header. [S18] [S1201]

Second, the sign-off locks the denominator to accepted output: kilograms of fabric or garments passing instrumental colour, fastness and dimensional inspection. [S37] Third, it sets product-family stratification rules so dark-shade reactive cotton batches are compared with dark-shade reactive cotton batches rather than bleached whites. [S02] [S36] Fourth, it records meter calibration certificates, missing-data rules and the residual between submeters and the billing meter. [S18] [S1203] Fifth, it budgets verification costs: FEMP cites a rule-of-thumb range in which annual M&V costs represent 2 to 5 percent of typical annual project cost savings, preventing management from approving hardware while omitting the submeters and laboratory checks needed to verify performance. [S1201]

> **GFT NOTE**
>
> **Freeze the baseline ledger before soliciting equipment quotations.** In GFT's Cameroon textile programme, no resource-saving capital expenditure should enter commercial evaluation without a locked baseline dossier containing at least 12 weeks of reconciled submeter readings, stratified by fabric construction and shade family, with accepted output as the sole denominator. [S18] [S29] When a greenfield plant has no historical operating record, supplier performance guarantees must be structured against a metered commissioning baseline established after line stabilisation, never against a generic regional average. [S08] [S1201]

12.4

Resource cost includes purchase, treatment and failure

Evaluating a water or energy project solely against the external utility tariff understates both the value of conservation and the operating cost of treatment hardware. [S01] [S06] [S1203] When a cubic metre of freshwater enters a wet-processing mill, the purchase fee or borehole levy is only the first entry in a cumulative cost chain. [S08] [S1203] That cubic metre must be pumped, filtered, softened, heated with steam in preparation and dyeing baths, dosed with auxiliary chemicals whose mass scales with bath volume, conveyed to the effluent treatment plant, dosed with coagulants or oxidants, aerated or pumped through membranes, and finally discharged under permit or concentrated into sludge requiring lawful disposal. [S01] [S06] [S31]

12.5 STACKED INTERNAL COSTS DWARF THE INTAKE TARIFF

Official water management guidance requires project appraisals to calculate combined water, energy, chemical and disposal cost changes across the process boundary. [S1203] In many textile regions, raw groundwater has been treated as a free input, masking its internal burden. [S08] The 2030 Water Resources Group and World Bank analysis of Bangladesh's textile sector documents that even where raw groundwater abstraction carries no municipal tariff, internal energy and purification costs range from US$12 to US$40 per tonne of fabric, averaging US$0.104 per cubic metre. [S08] Once that water becomes effluent, Appendix D of the World Bank study records operational costs of US$0.34 per cubic metre for a chemical effluent plant and US$0.21 per cubic metre for a biological plant, averaging US$0.308 per cubic metre across the surveyed mix. [S08] Before accounting for steam and dyebath chemicals, internal pumping, purification and effluent treatment total US$0.412 per cubic metre (US$0.104 plus US$0.308), nearly four times the abstraction cost alone. [S08]

Thermal energy amplifies the cost of process water further. [S01] [S16] Because wet-processing preparation, dyeing, printing and finishing demand 50 percent of total thermal energy in a composite plant, every unnecessary litre of hot bath or rinse water carries a fuel charge. [S16] A breakdown of thermal energy use in Japanese dyeing plants cited by Ernest Orlando Lawrence Berkeley National Laboratory (LBNL) shows that wastewater heat loss accounts for 24.9 percent of plant thermal energy consumption, exceeding the 16.6 percent used for product heating and the 17.2 percent used for drying. [S1202] Avoiding heating a cubic metre of water from an illustrative 25 degrees Celsius to 85 degrees Celsius saves steam enthalpy and bath chemicals that exceed volumetric water and effluent fees. [S01] [S02] [S1202]

12.6 WATER REUSE SHIFTS EXPENDITURE INTO ELECTRICITY, MEMBRANES AND CONCENTRATE

While source reduction in the dyehouse saves water, heat, chemicals and effluent treatment together, end-of-pipe water recycling presents a different cost structure because a recycled cubic metre is a manufactured utility stream consuming electricity, oxidants, membranes and sludge capacity. [S01] [S06] The industrial-park reuse case in Sanshui District, Foshan, China shows why whole-system cost accounting is mandatory before approving high-recovery membrane capital. [S06]

In the Foshan facility, textile effluent undergoes reactive precipitation, sand filtration, two-stage ozonation, ultrafiltration (UF) and reverse osmosis (RO), achieving an 86.8 percent reuse rate at a direct operating cost of US$0.44 per cubic metre of reused water. [S06] Combined sand filtration, UF and RO account for US$0.19 per cubic metre (with RO alone at US$0.14 per cubic metre), while ozone production accounts for US$0.18 per cubic metre because decolourising recalcitrant dye effluent requires 90 to 118 grams of ozone per cubic metre. [S06] Avoiding one cubic metre of water demand upstream through better preparation, right-first-time shade control or countercurrent washing saves intake, heating, bath-chemical and effluent costs together. [S01] [S37] Recovering 86.8 percent of wastewater through ozonation, UF and RO instead incurs treatment electricity, membrane and oxidant costs on every recovered cubic metre while leaving a 13.2 percent concentrate and sludge stream under wastewater guidelines. [S06] [S33] Capital allocation should rank upstream demand reduction and heat recovery ahead of tertiary reclamation unless water scarcity, discharge caps or intake tariffs justify membrane recovery. [S06] [S14]

12.7

Case paybacks guide screening, not approval

Technical compendia, equipment vendors and development-agency case studies frequently headline simple payback periods of a few months to three years for textile resource retrofits. [S07] [S27] [S1202] Those published figures are valuable for screening candidate engineering measures, but transporting a payback ratio from one country, tariff regime and factory configuration into another company's capital budget is an accounting error. [S1202] A payback period is not a physical property of a machine; it is the ratio of local installed capital cost to local net annual cash savings under a specific operating schedule. [S1202] [S1203]

12.8 PUBLISHED PAYBACK PERIODS DEPEND ON LOCAL TARIFFS, HOURS AND PRODUCT MIX

Consider three institutional references in the textile literature. First, under the United Nations Industrial Development Organization (UNIDO) MED TEST II programme in Tunisia, jeans manufacturer New Amico invested EUR 366,000 in two ozone-washing machines and three E-flow nanobubble machines, projecting a water reduction of 13 litres per pair of jeans and a payback under one year. [S07] Second, the United States Department of Energy's Steam Tip Sheet 3 reports that a boiler feedwater economizer can reduce fuel use by 5 to 10 percent and pay back in under two years; its worked example assumes an 80 percent efficient boiler generating 45,000 pounds per hour of 150-psig steam over 8,400 hours per year at a natural gas price of US$8.00 per million Btu. [S27] Third, LBNL's textile energy guidebook compiles costs and paybacks across wet-processing measures, including US$150,000 to US$890,000 (1.3 to 6.2 year payback) for automatic chemical dispensing, US$57,000 to US$150,000 (1 to 5 year payback) for automatic dye controllers, and US$143,000 to US$212,000 (1.3 to 3.6 year payback) for batch-dyeing cooling-water recovery. [S1202]

Each figure rests on boundary conditions that rarely hold unchanged in Central Africa. [S25] [S1202] LBNL notes that all reported savings, costs and paybacks apply only to reference conditions and that wherever a source lacked a payback figure, LBNL computed it assuming an electricity tariff of US$75 per MWh (US$0.075 per kWh). [S1202] Similarly, the DOE economizer example assumes 8,400 hours per year (95.9 percent

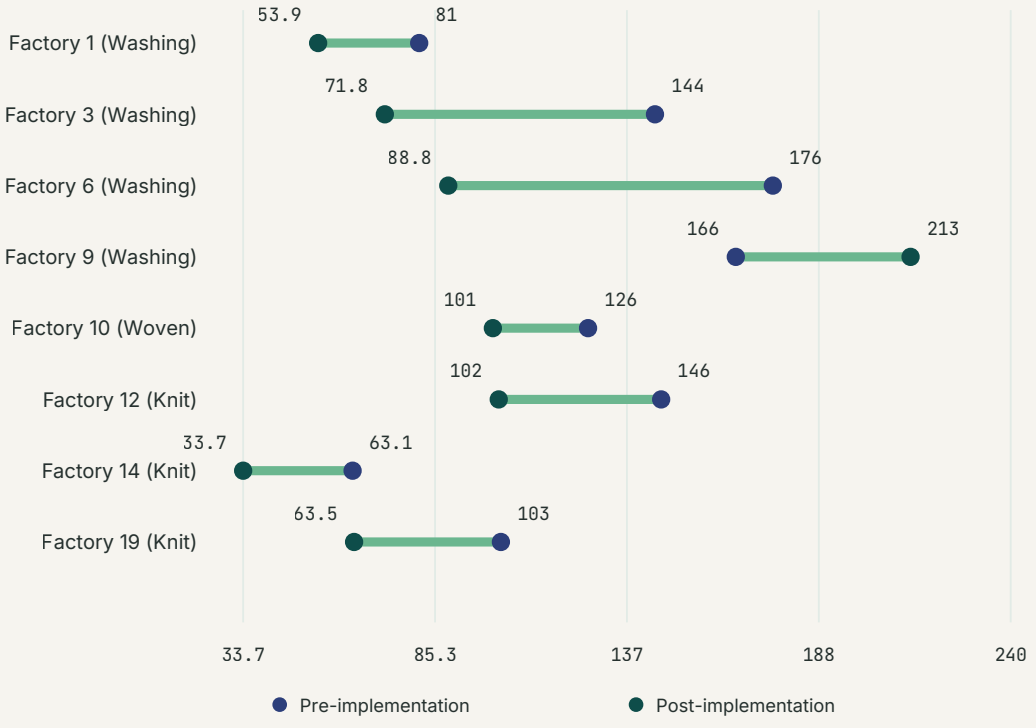
availability). [S27] If an African mill operates 4,000 hours per year, or faces customs duties, freight and commissioning charges that raise installed capital cost by 25 to 40 percent Illustrative above reference prices, a screening payback of 1.8 years stretches past 4.5 years Illustrative before process variance is considered. [S27] [S1202] Moreover, UNIDO's New Amico case reflects projections for denim washing rather than a general woven or knit dyehouse baseline. [S07]

12.9 CROSS-FACILITY BEFORE-AND-AFTER PAIRS SHOW WHY AVERAGES MISLEAD

Empirical multi-factory datasets confirm why project approval must rely on paired site measurements rather than sector averages. [S08] Appendix C of the 2030 Water Resources Group and World Bank report on Bangladesh collates pre-implementation and post-implementation resource intensity per kilogram of finished fabric across 33 textile and garment-washing factories in IFC's Water PaCT programme. [S08] **Exhibit 52**, p. 189 displays eight representative factory pairs from that appendix, spanning four garment-washing plants (Factories 1, 3, 6 and 9), one woven dyeing and printing mill (Factory 10), and three knit dyeing, finishing and printing mills (Factories 12, 14 and 19). [S08]

EXHIBIT 52 / LITRES PER KILOGRAM OF FABRIC

Factory cases demonstrate before-and-after measurement



SOURCED [S08] [S07] Pre-implementation and post-implementation specific water consumption across eight Bangladesh textile and garment-washing factories from Appendix C of the 2030 Water Resources Group and World Bank study (S08, pp. 41 to 42). Contrast these measured factory pairs, including Factory 9 where post-implementation intensity rose, with technology-specific projections such as the 13 litres per piece jeans-washing reduction projected in S07. None of these external figures is extrapolated to GFT.

Inspecting **Exhibit 52**, p. 189 alongside the full Appendix C table surfaces three lessons that a sector-wide saving percentage would hide. [S08] First, baselines vary nearly sixfold across the 33-factory sample, from 63.11 litres per kilogram at Factory

14 to 365.46 litres per kilogram at Factory 22. [S08] Second, while several facilities cut water intensity sharply, such as Factory 3 dropping from 144.34 to 71.77 litres per kilogram and Factory 6 dropping from 176.0 to 88.81 litres per kilogram, post-implementation water intensity rose in three factories: Factory 9 increased from 166.05 to 213.0 litres per kilogram, Factory 11 edged from 189.6 to 190.4 litres per kilogram, and Factory 25 moved from 215.0 to 217.8 litres per kilogram. [S08] Third, water reductions do not automatically pull every energy carrier down: at Factory 12 (73,500 kilograms per day), water fell from 146.0 to 102.37 litres per kilogram and power fell from 1.06 to 0.75 kWh per kilogram, but natural gas rose from 1.64 to 1.96 cubic metres per kilogram and steam rose from 8.6 to 9.6 kilograms per kilogram. [S08] Without multi-utility metering and mix normalisation, a single-resource business case can claim a water saving while concealing a thermal penalty. [S08] [S29]

12.10

Accepted output links resource return to production return

In a textile dyehouse or garment plant, resource efficiency and production quality are governed by the same physical chemistry and machine control loops. [S31] [S37] An intervention that reduces bath volume, lowers wash temperature or shortens stenter dwell time saves money only if the resulting fabric or garment passes release inspection on the first attempt. [S16] [S37] If a low-liquor or low-temperature modification reduces dye fixation, causes shade unlevelness or leaves residual salt on the cloth, the batch must be stripped, re-dyed, given extra hot rinses or downgraded. [S31] [S36] [S37] Because right-first-time dyeing governs water, energy, effluent, machine time and colour cost, any valuation model that ignores first-pass yield can approve an investment that erodes factory margin. [S37]

12.11 THE RECONCILIATION EQUATION SEPARATES RESOURCE SAVINGS FROM VOLUME EFFECTS

To prevent double-counting between utility savings and production volume changes, GFT structures capital appraisal around an M&V reconciliation equation grounded in ISO 50001 baseline logic and FEMP retrofit-isolation accounting. [S18] [S1201] For any resource stream `r` across a reporting period of accepted output `Q_acc,1`, net verified annual project cash flow (`V_net`) is:

`V_net = sum_r [ (E_adj,0,r - E_1,r) * P_r ] + delta_M_qual - delta_C_O&M - C_M&V` (illustrative valuation equation derived from standard M&V accounting). [S18] [S29] [S1201]

In this illustrative formulation, `E_adj,0,r` is baseline consumption of resource `r` adjusted to the reporting period's accepted output `Q_acc,1` and product mix; `E_1,r` is actual metered consumption during the reporting period including all utilities consumed by rejected, stripped or re-washed batches; `P_r` is the unit price of resource `r`; `delta_M_qual` is the verified change in non-utility production costs (such as dyestuff mass avoided through higher right-first-time yield, excluding utilities counted in the first term); `delta_C_O&M` is incremental operating, maintenance and sludge cost; and `C_M&V` is annualised verification cost. [S18] [S29] [S1201]

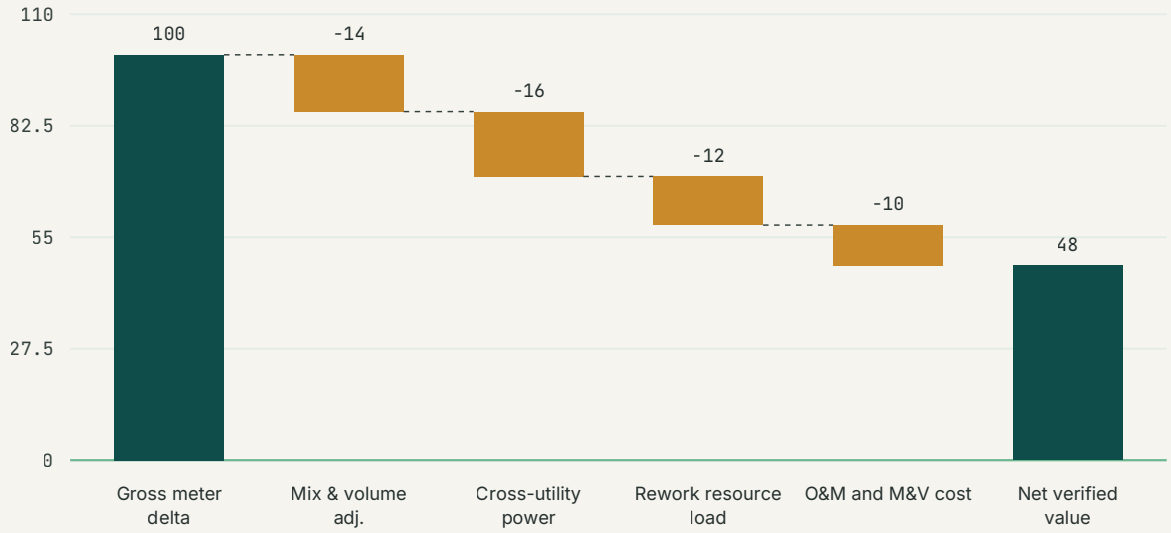
WHOLE-CYCLE UNIT-SAVING VALUATION BOUNDARY

1. **Define the accepted-unit denominator (`Q_acc`):** Count only kilograms of fabric or garments that pass shade tolerance, fastness and physical inspection. [S31] [S37]
2. **Keep rework inside the numerator (`E_1,r`):** Meter all water, steam, power and chemicals used in initial processing, shading additions, stripping, re-dyeing and extra rinsing inside `E_1,r`. [S37]
3. **Adjust the baseline to comparable output (`E_adj,0,r`):** Apply the locked product-family baseline rate or regression equation to `Q_acc,1` so volume shifts are not misclassified as efficiency changes. [S29] [S1201]
4. **Sum all affected utilities with signs preserved:** Include negative savings (such as higher electricity demand for reverse-osmosis pumps, ozone generators or jet circulation pumps) alongside water or steam reductions. [S06] [S1202]
5. **Prevent double-counting of production effects:** Because `E_adj,0,r - E_1,r` already captures utilities saved by avoiding re-dyes, `delta_M_qual` includes only non-utility items such as avoided dyestuff mass. [S37] [S1201]

Exhibit 53, p. 191 illustrates how this accounting bridge filters an exaggerated gross meter delta down to net verified project value before capital is committed. [S18] [S29] [S1201]

EXHIBIT 53 / ILLUSTRATIVE INDEX (GROSS METER DELTA = 100)

Annual project value starts with accepted-unit savings



ILLUSTRATIVE [S18] [S29] [S1201] Illustrative valuation bridge showing how an apparent gross utility reduction (indexed to 100 units) is adjusted for baseline product-mix and volume normalisation, cross-utility electricity additions, reprocessing penalties on off-shade batches, and incremental operating, maintenance and M&V costs to arrive at net verified project value. Structure derived from S18, S29 and S1201; values are illustrative.

In **Exhibit 53**, p. 191, an unadjusted meter comparison suggests 100 illustrative units of gross annual savings. Normalising for fabric weights and seasonal line loading removes 14 illustrative units attributable to schedule mix. [S29] Accounting for extra power drawn by circulation pumps or membranes removes 16 illustrative units. [S06]

[S1202] Charging the water and steam consumed by reprocessed batches back against accepted output removes 12 illustrative units, and deducting maintenance consumables plus a 3 percent M&V allowance removes 10 illustrative units, leaving 48 illustrative units of net verified annual value. [S37] [S1201]

12.12 REPROCESSING AND CROSS-UTILITY PENALTIES CAN ERASE NOMINAL BATH SAVINGS

Experimental and industrial evidence shows why cross-utility and quality deductions are material in wet processing. [S36] [S1202] On the chemistry side, reactive dye fixation at reduced liquor ratios depends on molecular structure: at a 1:6 liquor ratio on cotton fabric, measured fixation rates for three reactive yellow dyes (MRY-1, MRY-2 and MRY-3) were 84.9 percent, 71.1 percent and 75.0 percent respectively. [S36] A 13.8 percentage-point drop in fixation leaves nearly twice as much unfixed chromophore in the bath, requiring heavier hot washing to meet fastness specs and raising shade-correction risk. [S31] [S36] On the mechanical side, LBNL's dataset notes that jet dyeing optimization saves 1.8 to 2.4 kilograms of steam per kilogram of fabric, but raises electricity use by 0.07 to 0.12 kWh per kilogram of fabric for liquor circulation, against a capital cost of US$221,000 per machine and a reference payback of 1.4 to 3.1 years. [S1202]

WORKED EXAMPLE: ILLUSTRATIVE WHOLE-CYCLE VALUATION OF A LOW-LIQUOR AND RINSE-CONTROL RETROFIT

Consider an **illustrative** paired-trial analysis for a cotton batch-dyeing line processing `Q_acc,1 = 1,000,000` accepted kilograms per year of reactive-dyed knit fabric. All figures, tariffs and quotes below are **illustrative** assumptions; the XAF-to-EUR peg of 655.957 XAF per euro follows `[^R32]` (using an illustrative 600 XAF per US$1.00).

1. **Adjusted baseline (`E_adj,0`):** Achieving 1,000,000 accepted kilograms in the illustrative baseline required 1,060,000 gross kilograms (6.0 percent rework) at 110.0 litres of water per accepted kilogram (110,000 cubic metres per year), 6.50 kilograms of steam per accepted kilogram (6,500 tonnes per year), and 0.90 kWh of electricity per accepted kilogram (900,000 kWh per year).
2. **Reporting-period consumption (`E_1`):** An illustrative low-liquor and conductivity-rinse retrofit yields verified consumption across 1,000,000 accepted kilograms (including re-dyes) of 78.0 litres of water per accepted kilogram (78,000 cubic metres per year), 4.80 kilograms of steam per accepted kilogram (4,800 tonnes per year), and 1.00 kWh of electricity per accepted kilogram (1,000,000 kWh per year, reflecting 0.10 kWh per kilogram higher pump load `[^S1202]`).
3. **Physical net deltas (`delta_E`):** Under this illustrative balance, water and effluent avoided is `110,000 - 78,000 = +32,000` cubic metres per year; steam avoided is `6,500 - 4,800 = +1,700` tonnes per year; and electricity change is `900,000 - 1,000,000 = -100,000` kWh per year.
4. **Monetary valuation (`P_r`):** At an illustrative combined water and effluent cost of 480 XAF per cubic metre (US$0.80 `[^S08]`), water saving is `+15,360,000` XAF per year (US$25,600). At an illustrative steam cost of 21,000 XAF per tonne (US$35.00), thermal saving is `+35,700,000` XAF per year (US$59,500). Verified salt and alkali reduction (`delta_M_qual`) adds an illustrative `+8,940,000` XAF per year (US$14,900), while electricity at an illustrative 75 XAF per kWh (US$0.125) imposes a `-7,500,000` XAF per year (minus US$12,500) penalty.
5. **Net verified cash flow (`V_net`):** Gross illustrative saving equals `52,500,000` XAF per year (US$87,500). Deducting an illustrative 4,200,000 XAF per year (US$7,000) for maintenance plus 1,800,000 XAF per year (US$3,000, or 3.4 percent of gross savings, within FEMP's 2 to 5 percent M&V band `[^S1201]`) leaves `V_net = 46,500,000` XAF per year (US$77,500).
6. **Simple payback:** Against an illustrative installed cost of 139,500,000 XAF (US$232,500), verified simple payback is `139,500,000 / 46,500,000 = 3.00` years, compared with 2.3 years Illustrative if the pump penalty and O&M/M&V deductions were omitted.

12.13

Sensitivity analysis belongs in the investment paper

A single-point payback estimate conceals the operating variance that determines whether a textile factory recovers its capital. `[S16]` `[S29]` Four sources of variance dominate post-installation financial performance: utility tariffs and fuel-to-electricity price spreads, plant capacity utilisation, right-first-time quality stability across changing shade portfolios, and physical degradation of heat-transfer, membrane or sensor

hardware over time. [S06] [S16] [S29] [S37] Every investment paper submitted for GFT review should therefore present a multi-parameter sensitivity range rather than a single deterministic payback. [S16]

12.14 TARIFF SPREADS AND CAPACITY UTILISATION DRIVE PAYBACK DISPERSION

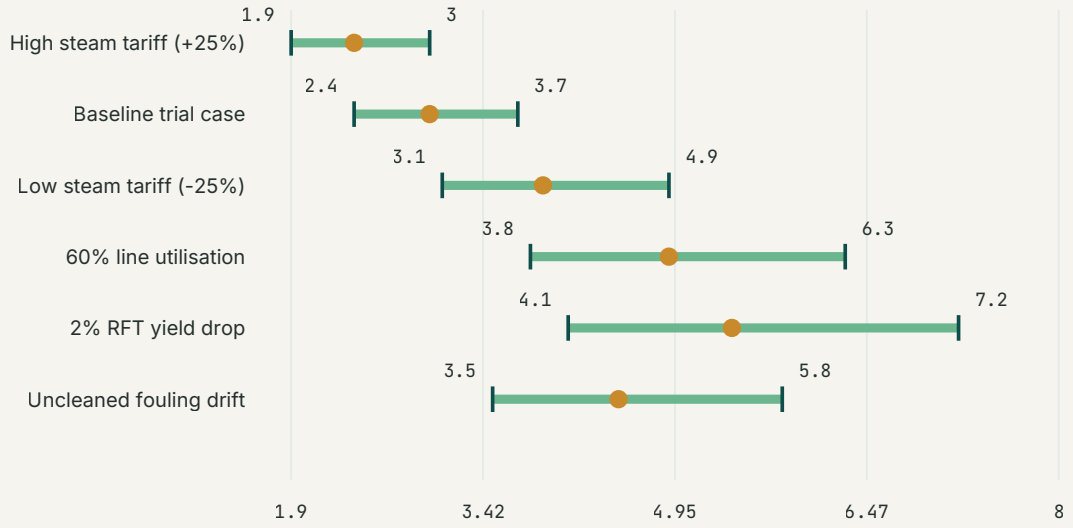
The techno-economic analysis of electrified process heating in textile wet processing across China, Japan and Taiwan shows how strongly relative energy prices control project economics. [S16] Switching from combustion boilers to electrified heating or industrial heat pumps reduced final thermal energy demand, yet unit production cost remained sensitive to local electricity and fuel tariffs, while capital costs lay outside parts of the unit-energy comparison. [S16] Where electricity is expensive relative to fuel, a measure that saves steam while adding electrical load sees its net savings compress. [S06] [S16] [S1202]

Capacity utilisation is equally decisive in African textile industrialisation. [R12] [S25] In Cameroon, July 2023 reporting on the incumbent manufacturer CICAM recorded capacity utilisation of 33.7 percent at Garoua, 48.9 percent at CICAM 1 and 10.83 percent at CICAM 2, with underutilisation costing about CFAF 2 billion in 2020. [R12] While those figures describe a state-owned incumbent rather than a GFT facility, they illustrate a concrete risk: if a retrofit is justified assuming 8,000 hours per year, and accepted throughput runs at 40 percent of capacity, variable savings fall in proportion to $Q_{acc,1}$ while lower volume raises fixed standby losses per unit ($R^2 = 0.6404$). [R12] [S29] [S1201] Greenfield announcements in Cameroon also reflect long capital horizons: the announced Camtext SA project (US$300 million, or 180 billion XAF, processing 12,000 tonnes a year) projects a return on investment near 11 years and optimal capacity around 2033. [R09] [R10] Resource projects must therefore be stress-tested against phased ramp-up volumes. [R10] [S29]

Exhibit 54, p. 195 shows how simple payback expands into a decision range when tariff, utilisation, quality and maintenance assumptions vary. [S16] [S29] [S1202]

EXHIBIT 54 / ILLUSTRATIVE SIMPLE PAYBACK (YEARS)

Payback remains a range under operating uncertainty



ILLUSTRATIVE [S16] [S29] [S1202] Illustrative simple-payback sensitivity bands across six operating scenarios for the worked-example wet-processing retrofit (central baseline payback 3.0 years). Bars show low, midpoint and high payback years under varying utility tariffs, line utilisation, right-first-time yield and heat-exchanger or membrane fouling. Sensitivity mechanisms follow S16, S29 and S1202; numeric bounds are illustrative.

In **Exhibit 54**, p. 195, the illustrative baseline trial case centres on a 3.0-year payback (range 2.4 to 3.7 years). A 25 percent higher steam tariff Illustrative shortens midpoint payback to 2.4 years, whereas a 25 percent lower steam tariff Illustrative lengthens it to 3.9 years. [S16] At 60 percent line utilisation, midpoint payback stretches to 4.9 years (high bound 6.3 years). [S29] A 2 percentage-point drop in right-first-time dyeing yield pushes midpoint payback to 5.4 years and the high bound to 7.2 years, because each failed batch consumes another cycle of water, steam, chemicals and machine hours without adding to accepted output. [S37]

12.15 SAVING PERSISTENCE REQUIRES SCHEDULED RECALIBRATION AND MAINTENANCE ALLOWANCES

The sixth bar in **Exhibit 54**, p. 195, uncleaned fouling drift, highlights the decay of savings persistence after commissioning. [S1201] In textile wet processing, hot wastewater carries lint, size residues, waxes, unfixed dyes and salts. [S01] [S02] Heat-exchanger coefficients and membrane flux decline unless backflushing, lint screening and chemical cleaning-in-place run on schedule and are budgeted in `delta_C_O&M`. [S06] [S17] Conductivity probes, pH electrodes and flow meters also drift in hot alkaline baths, causing controllers to revert toward over-rinsing if calibration is neglected. [S1201] FEMP lists assessing savings persistence and improving maintenance among the core goals of M&V. [S1201] Capital proposals whose cash flows omit cleaning downtime, spare membranes and sensor recalibration should be returned as incomplete. [S06] [S1201]

12.16

A stage gate protects cash and evidence

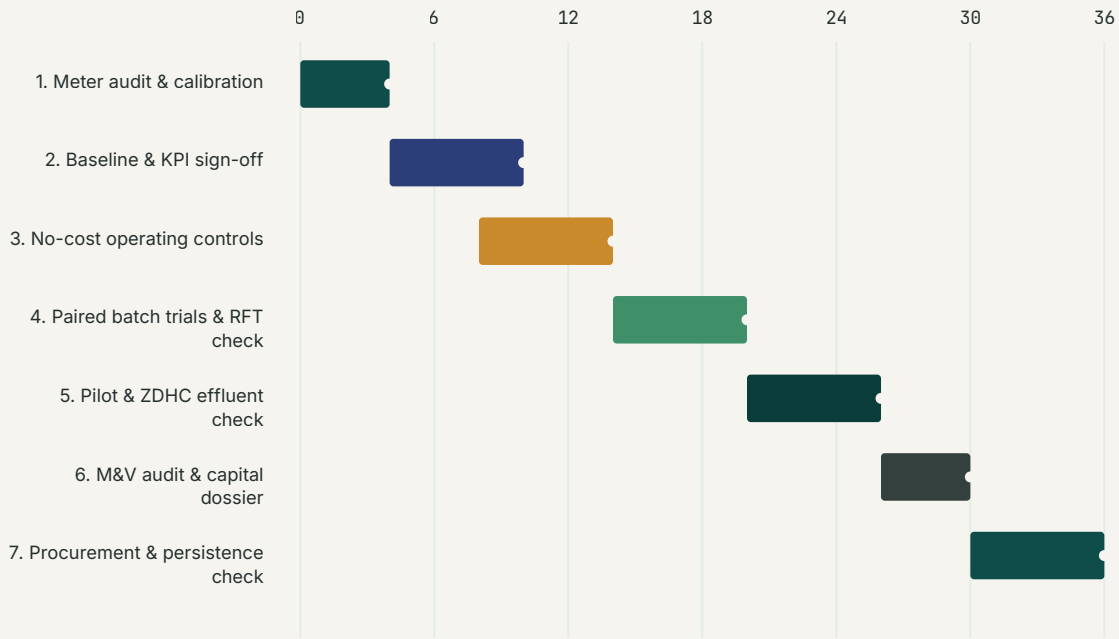
Because no-cost operational controls capture a large share of available resource reductions, and because hardware retrofits carry quality and burden-shifting risks, GFT governs resource investments through a strict stage-gate sequence. [S01] [S17] [S18] Each project must pass progressive evidence gates where failure to meet product quality or effluent conformance halts progression. [S33] [S37]

12.17 SEQUENTIAL EVIDENCE GATES FILTER OUT UNVERIFIED CAPITAL REQUESTS

Exhibit 55, p. 196 maps the seven-stage evidence and capital sequence across an illustrative 36-week planning window, derived from ISO 50001 management cycles, FEMP M&V planning steps, right-first-time experimental design and ZDHC wastewater checks. [S18] [S33] [S37] [S1201]

EXHIBIT 55 / ILLUSTRATIVE PROGRAMME WEEKS FROM GATE ZERO

Evidence gates precede the capital gate



DERIVED [S18] [S33] [S37] [S1201] Derived seven-stage governance sequence requiring meter calibration, baseline sign-off, no-cost operational controls, paired batch trials, pilot verification and an independent M&V audit before full capital procurement and persistence tracking. Governance, quality and effluent stop rules are derived from S18, S33, S37 and S1201; the 36-week timeline is an illustrative planning window.

As shown in **Exhibit 55**, p. 196, the sequence separates low-cost measurement and operational discipline from capital expenditure:

1. **Gate 1: Meter audit and calibration (Weeks 0 to 4 Illustrative).** Utilities and laboratory teams verify intake, boiler, compressor and process submeters against bills, trace drain lines, and calibrate spectrophotometers, pH meters and conductivity sensors. [S18] [S1203]

2. **Gate 2: Baseline and KPI sign-off (Weeks 4 to 10 Illustrative).** Engineering and finance lock the baseline period, accepted-output denominator (`Q_acc`), normalisation equations, residuals and FEMP Option A or Option B plan. [S18] [S29] [S1201]
3. **Gate 3: No-cost operating controls (Weeks 8 to 14 Illustrative).** The plant executes housekeeping fixes: repairing steam and air leaks, returning condensate, enforcing rinse endpoints, optimising loads and removing extra stenter passes. [S01] [S16] [S17] Savings achieved here update the baseline downward so capital is judged only on remaining incremental reductions. [S1201]
4. **Gate 4: Paired batch trials and right-first-time check (Weeks 14 to 20 Illustrative).** Candidate modifications run on paired lots matched by fibre, fabric mass and shade depth, recording exhaustion, fixation, colour difference, fastness and re-dyes alongside metered resources. [S31] [S36] [S37]
5. **Gate 5: Single-line pilot and effluent verification (Weeks 20 to 26 Illustrative).** A pilot machine or skid runs across a shade matrix while effluent and sludge samples are tested against ZDHC Wastewater Guidelines parameters to verify that lower water volume causes no concentration breach. [S06] [S33] [S1201]
6. **Gate 6: Independent M&V audit and capital dossier (Weeks 26 to 30 Illustrative).** Finance and sustainability audit the pilot balances, compute `V_net` from site quotes, run the sensitivity band across tariff, utilisation, RFT yield and fouling scenarios, and submit the dossier. [S16] [S1201]
7. **Gate 7: Conditional procurement and persistence tracking (Weeks 30 to 36 Illustrative and ongoing).** Rollout proceeds after Gate 6 approval, with supplier retention tied to verified performance per accepted unit over an operating cycle. [S18] [S1201]

12.18 HARD STOP RULES PREVENT RESOURCE PROJECTS FROM DEGRADING PRODUCT OR EFFLUENT COMPLIANCE

GFT embeds three non-negotiable stop rules inside Gates 4, 5 and 6. [S33] [S37] First is the **quality stop rule**: if a candidate measure increases colour-difference rejection, lowers wash or rubbing fastness below specification, causes dimensional instability, or reduces right-first-time pass rate against matched controls, the measure is halted regardless of its meter reduction. [S16] [S37] Second is the **effluent and chemical stop rule**: if a recipe change lacks Safety Data Sheets and ZDHC MRSL conformance documentation, or if pilot effluent testing shows spikes in chemical oxygen demand, biochemical oxygen demand, total dissolved solids or restricted substances exceeding treatment capacity, the trial fails Gate 5. [S31] [S32] [S33] Third is the **burden-shifting stop rule**: if cross-utility electricity additions, concentrate disposal or Scope 2 grid emissions outweigh the primary saving at the site's grid factor and tariff structure, the project is rejected. [S06] [S16] [S19]

UNRESOLVED SITE INPUTS AND LIMITS OF THIS FRAMEWORK

This chapter defines the accounting equations, evidence gates and stop rules required to evaluate resource-efficiency investments, but it cannot supply site-specific Cameroonian water tariffs, effluent charges, borehole permitting costs, contractor quotes or ENEO grid reliability profiles, which must be collected during due diligence ([^S12], [^S15], [^S25]). Neither the external factory cases from Bangladesh, China, Tunisia and Latvia ([^S06], [^S07], [^S08], [^S29]) nor the illustrative worked example represents realized GFT performance or a guarantee of return. Sponsors must pair this engineering protocol with formal capital budgeting, legal permitting and independent financial advice.

When a project clears all six pre-capital gates, its verified parameters feed into GFT's wider analytical system: the batch-level data spine in Chapter 13 records persistence, Chapter 14 embeds the project into daily, weekly and monthly management cadence, and the verified unit-saving distributions populate GFT's `unit-economics`, `footprint` and `ramp-planner` decision tools alongside `wp13`, `wp15` and `wp02`. [S18] [S29] Refusing to separate financial return from accepted output ensures that every franc or dollar invested in sustainability strengthens production control. [S18] [S37]

A saving is investable only when it survives the meter, the quality release gate and the whole-cycle cost ledger on every accepted unit.

CHAPTER SOURCE NOTES

S18 International Organization for Standardization. 2018.

S37 Emerald Publishing Limited. 2019.

S1202 Ernest Orlando Lawrence Berkeley National Laboratory. 2010-09.

S29 Sciendo, Riga Technical University, Environmental and Climate Technologies. 2021-06-28.

S1201 United States Department of Energy, Federal Energy Management Program. 2015-11.

R06 Cameroon Trade Hub. Publication date unrecorded; inherited source-text check.

R07 Ecofin Agency. Publication date unrecorded; inherited source-text check.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S27 United States Department of Energy, Advanced Manufacturing Office. 2012.

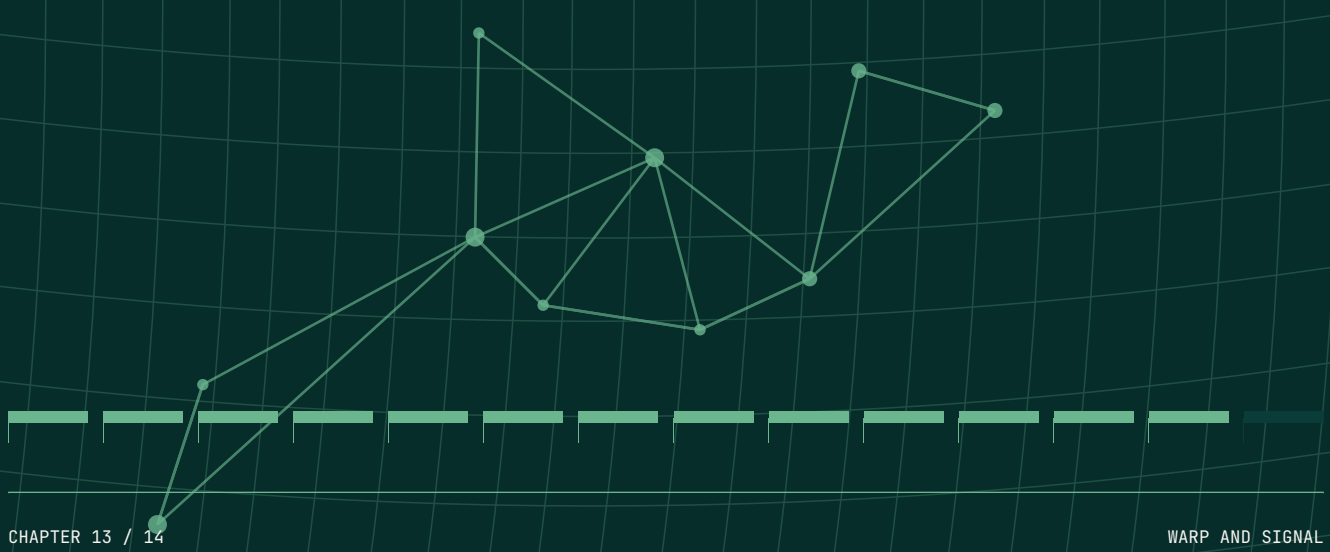
S02 European Commission Joint Research Centre. 2023.
S24 Sustainable Apparel Coalition. 2022.
S36 Elsevier, Dyes and Pigments. 2024.
S1203 United States Environmental Protection Agency. 2012-10.
S08 2030 Water Resources Group, World Bank. 2015.
S06 MDPI, Processes. 2019-01-11.
S31 Springer Nature, Scientific Reports. 2022-12-26.
S16 MDPI, Energies. 2022-11-25.
S33 ZDHC Foundation. 2024.
S14 Sweden Textile Water Initiative, Stockholm International Water Institute. 2017.
S07 United Nations Industrial Development Organization. 2018-03-22.
S25 World Bank. 2025-06-25.
R32 Wise; XE. Publication date unrecorded; inherited source-text check.
R12 Business in Cameroon. Publication date unrecorded; inherited source-text check.
R09 Ecofin Agency. Publication date unrecorded; inherited source-text check.
R10 Ecofin Agency. Publication date unrecorded; inherited source-text check.
S17 United States Department of Energy and Industrial Heating Equipment Association. 2015.
S32 ZDHC Foundation. 2023.
S19 GHG Protocol. 2015.
S12 Food and Agriculture Organization of the United Nations and UN-Water. 2024.
S15 World Health Organization. 2025-09-26.

13

PART IV: GFT'S MEASUREMENT AND REDUCTION SYSTEM / THE OPERATING RECORD

A batch-level data spine turns meters into management

Resource data becomes useful when it carries the identity of the fabric, recipe, machine and quality decision that produced it.



CHAPTER 13
DECISION TEST

Resource data becomes useful when it carries the identity of the fabric, recipe, machine and quality decision that produced it.

A resource ledger should connect each meter interval to a production event, a material identity and a quality decision, then reconcile those assignments to the factory total. GFT recommends this batch-level data spine as the operating record for water, chemistry and energy. Its purpose is to make exceptions explainable and corrective action testable. The design below is proposed, not an installed GFT system. It specifies the information needed to manage resource intensity; it does not claim that collecting data alone produces a saving.

13.1

The meter hierarchy reconciles detail to the utility bill

Begin with the resource boundary, not the dashboard. ISO 50001 describes a systematic energy-management framework and identifies performance indicators and baselines as monitoring tools. The Sustainable Apparel Coalition's December 2022 technical paper describes separate water and energy reporting for different facility types within an integrated site. That paper explicitly warned that its forthcoming final framework could differ. These are methodological reference points, not a claim of present assessment compliance. [S18] [S24]

For the proposed ledger, the utilities owner should draw the physical meter tree beside the process route. Incoming freshwater, purchased electricity, fuel receipts and purchased heat need separate accounts. Downstream branches should identify preparation, dyeing, rinsing, drying, garment operations and shared services wherever those operations fall inside the actual boundary. A meter must have an asset identity, location, measured medium, unit, direction, reading convention and effective installation dates. A useful branch answers an operating question; more branches do not automatically improve the account.

GFT recommends preserving raw cumulative readings and calculating interval differences through a versioned rule. Record the opening and closing times, not just the shift label. Flag meter resets, rollover, replacement and suspect reverse movement before calculating consumption. Keep the raw register unit beside the converted reporting unit. If a pulse multiplier changes, apply its effective date to the relevant observations and retain the earlier configuration. A replacement meter should start a new measurement segment rather than inherit the old register as though nothing happened.

The reporting total should reconcile to the supply account over the same time window. For freshwater, assign incoming volume to process withdrawals, shared uses, relevant storage changes and a visible residual. Internal reuse requires transfer records so circulation is not counted again as fresh supply. For electricity, reconcile the incoming and generation boundaries before assigning machine and shared demand. Fuel converted to steam requires a conversion account; adding both as independent purchased resources would count the same input again. These are proposed accounting controls, to be checked against the installed utility arrangement.

A residual is an investigation item, not a convenient product allocation. It may contain unmetered demand, timing differences, meter error or an incorrect connection map. The utilities owner should classify explanations and retain an unresolved remainder.

GFT recommends setting an investigation rule from meter specifications, operating variability and the decision at risk, rather than inventing a universal percentage tolerance. A small unexplained balance can still matter when the claimed improvement is smaller. A large balance should prevent a precise batch-saving claim even when the dashboard looks stable.

For shared steam, the proposed meter tree should retain the measurement actually available. If the plant measures steam mass but not the conditions needed to calculate delivered thermal energy, report mass with that limitation. Do not present a heat figure as directly measured merely because a conversion factor exists. Retain the factor, pressure and temperature basis, relevant condensate assumption and method owner with any calculation. Where process demand is allocated from machine runtime, keep standby demand separately visible so an idle shift does not disappear from the resource account.

Concurrent batches need an explicit allocation decision. If a branch meter supplies several operating machines, its total supports the branch account but does not independently measure each machine. GFT recommends testing whether event timing, temporary measurements or another defensible driver can divide that quantity. Record the allocation status beside each batch result. Where the evidence cannot support division, compare the combined production window instead. Installing another meter is justified when the missing distinction could change a consequential decision, rather than because the data model contains an empty field.

The proposed hierarchy in **Exhibit 56**, p. 203 places calculations between observations and decisions. This separation matters: a corrected allocation should change a calculated view without rewriting the original reading. Product reporting sits above the operational account because it needs additional boundaries and methods. The diagram specifies information responsibilities, not equipment procurement, software selection or evidence that a particular implementation works.

EXHIBIT 56 / PROPOSED INFORMATION RESPONSIBILITIES

Decisions retain a route back to the observation



ILLUSTRATIVE [S18] [S20] [S24] Illustrative GFT design informed by management and inventory principles. No installed system is represented.

GFT NOTE

Approve the meter tree and reconciliation rule before commissioning the dashboard. Keep unallocated resource visible until an authorised method assigns it. Spend first on observations that can change a process decision, particularly where an uncertain balance could exceed the improvement being tested.

13.2

Batch genealogy is the join between resource and quality

Batch identity should survive correction, splitting, merging and delayed release. GFT recommends a permanent batch identifier with linked processing-event identifiers, rather than a mutable spreadsheet row combining every operation. Retain the incoming fabric lot, fibre description, construction, shade target, style where relevant, machine, recipe version and actual route. Each event should carry its start and finish, resource observations and disposition. These are proposed minimum fields for a resource account, not a universal production schema.

The reason to retain water and recipe conditions beside the quality outcome is practical. The opened right-first-time dyeing study reports that water hardness and dye concentration affected the modelled colour results in its experimental setting. It

also connects avoiding corrective reprocessing with resource use. Those findings support investigating process conditions together; they do not establish a Cameroon operating result or a transferable prediction model. [S37]

Under the proposed genealogy, a failed shade decision should create a correction event linked to the same material lineage. Keep the original processing consumption, subsequent additions and final release visible. Reprocessing must not create another apparent saleable quantity merely because the fabric passed through a machine again. When a batch splits, record the actual child quantities and their basis. When batches merge, retain every parent and avoid attributing the combined output solely to the most recent input. Quantity checks should expose unexplained losses rather than force the genealogy to balance.

Quality release should be a dated event owned by an authorised role. The record needs accepted, held, rejected and reprocessing states with quantities and reasons. For management reporting, GFT recommends distinguishing consumption incurred during the reporting period from the resource history of batches completed during that period. A batch crossing the period boundary otherwise creates a misleading ratio. A period account should carry opening and closing work in progress; a completed-batch account should carry its full route, including earlier events. Reconcile their differences rather than mixing them silently.

The compact dictionary in **Exhibit 57**, p. 204 groups the proposed fields by question. The groups are deliberately resource-specific. They give the process engineer enough context to explain water, chemistry, heat and quality variance while leaving broader enterprise governance and technical architecture to the companion papers. Their presence alone does not prove traceability: relationships, quantities and effective versions must also pass validation.

EXHIBIT 57 / PROPOSED FIELD GROUPS AND CHECKS

Each resource value needs an identity and a boundary

Record	Retain	Validate
Material	Lot, parents, children	Quantity lineage
Process	Recipe, machine, times	Effective version
Resource	Meter, interval, unit	Reading and boundary
Release	Status, mass, decision	Authorised event
Sample	Location, method, time	Coverage and identity
Calculation	Rule, status, owner	Reproducible inputs

ILLUSTRATIVE [S24] [S33] [S37] Illustrative GFT data dictionary. These fields are recommendations, not a source-mandated software schema.

WORKED EXAMPLE: REPROCESSING REMAINS ATTACHED TO THE BATCH

An illustrative batch starts with 500 kg of fabric and uses 25,000 litres in its original wet-processing route. Assume that 100 kg requires correction using another 4,000 litres, and that 480 kg is ultimately accepted. The remaining 20 kg is rejected. The completed-batch intensity is therefore (25,000 + 4,000) / 480 = 60.42 litres per accepted kilogram, rounded to two decimal places. Counting only the original route against all input fabric would give 25,000 / 500 = 50 litres per kilogram. That is a different, incomplete measure. The assumptions demonstrate record logic, not expected factory performance.

In this illustrative example, assuming that both process volumes are independently measured, the observations may be measured while the ratio is calculated. The correction still belongs to the original material lineage. Final acceptance must count the accepted fabric once, including corrected fabric, rather than count its extra machine passage as new output. A later quality reversal would require a revised calculation with the earlier report retained.

Chemical issue records need the same discipline. GFT recommends recording actual dispensed quantities, product and supplier lot identifiers, recipe additions, returns and authorised substitutions. Keep the as-supplied quantity separate from any active-substance conversion, whose composition basis should be retained. A recipe target is a planned input; an issue from stores is not automatically a measured addition to the bath. The ledger should distinguish those events before a resource owner investigates dosing variance or compares recipes. This avoids treating purchasing, inventory movement and process consumption as interchangeable observations.

13.3

Laboratory and utility data must share identifiers

A laboratory result becomes useful to the resource ledger when its sampling boundary is explicit. The September 2024 ZDHC Wastewater Guidelines distinguish untreated wastewater, discharged wastewater and sludge, and link sampling arrangements to discharge configuration. They also explain that MRSL testing of untreated wastewater serves chemical-input investigation. The guidance does not replace legal requirements. This supports keeping sample purpose and location explicit; it does not mean a final-discharge result identifies the contribution of an individual production batch. [S33]

GFT recommends a sample record containing a permanent identifier, collection start and finish, physical location, sample type, requested analysis, applicable method version and linked production events. Record who collected and analysed it, the laboratory report reference, receipt condition and any preservation exception. Results need units, reporting limits and qualification flags. Keep a result below a reporting limit distinguishable from a numerical zero. A corrected laboratory report should supersede the earlier version visibly, with its reason retained, rather than replace the original attachment without explanation.

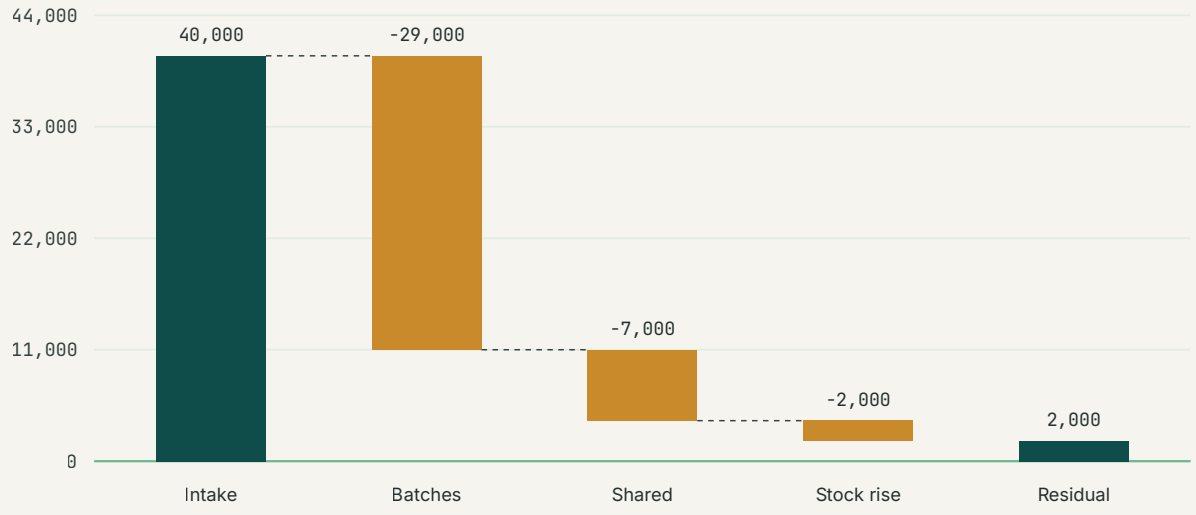
For colour, fastness, fixation, pH and conductivity, use the same event and material references as the process history. The proposed record should retain the analytical or instrument method, calibration evidence relevant to the measurement, sample preparation and decision rule. Fixation and colour release answer different questions and should not occupy a shared field. A process engineer should be able to inspect the result behind a quality decision without assuming that an acceptable shade also proves an acceptable effluent outcome.

Effluent attribution needs particular restraint. Where discharge from several operations enters an equalisation tank, GFT recommends linking a downstream sample to a contributing production window and tank condition. Do not assign it to the last batch completed merely because its timestamp is nearest. A mixed-stream concentration should remain a mixed-stream observation. A calculated pollutant load needs a compatible flow record and sampling basis. If that relationship is unavailable, report concentration and flow separately with the limitation, rather than manufacture a batch-specific load.

The illustrative balance in **Exhibit 58**, p. 206 explains another attribution boundary. The incoming volume is assumed to be 40,000 litres over an aligned window. Assumed batch allocations total 29,000 litres, shared uses total 7,000 litres and tank stock rises by 2,000 litres. The unexplained residual is 40,000 minus 29,000 minus 7,000 minus 2,000 = 2,000 litres. No internal reuse is included. These constructed quantities demonstrate reconciliation only; they do not describe an observed factory.

EXHIBIT 58 / ILLUSTRATIVE LITRES IN ONE ALIGNED WINDOW

An unexplained balance remains visible after allocation



ILLUSTRATIVE Assumed intake 40,000; less batches 29,000, shared uses 7,000 and stock rise 2,000; residual 2,000. No reuse included.

Retain measurement conditions when comparing laboratory results. GFT recommends checking whether samples share a preparation method, reporting basis and relevant process stage before plotting an apparent trend. A conductivity measurement during rinsing should retain the stream and process conditions required by its approved

method. A result from a different location can be useful but should not silently extend the earlier series. Method changes should carry a break marker or a documented comparison, so an analytical change cannot become an apparent operating improvement.

The balance cannot identify the cause of the remainder. GFT recommends tracing possible explanations through tank readings, meter timing, washing records and unmetered services before allocating it to product. Laboratory and utility owners should resolve their own observation exceptions, then jointly review any proposed connection between resource variance and effluent quality. That review should preserve competing explanations until evidence discriminates between them. A convincing narrative is not a substitute for a compatible measurement boundary.

13.4

Edge capture should survive power and connectivity limits

Design for interruption as a condition to test, not as a site fact already established. The World Bank's June 2025 implementation report describes an ongoing Cameroon power-sector reform programme and transmission and distribution investment. It does not establish the reliability, interruption duration or electricity quality at a proposed factory. GFT recommends a site power and communications survey before selecting power protection, buffer capacity or transmission equipment. National programme context cannot size the local capture system. [S25]

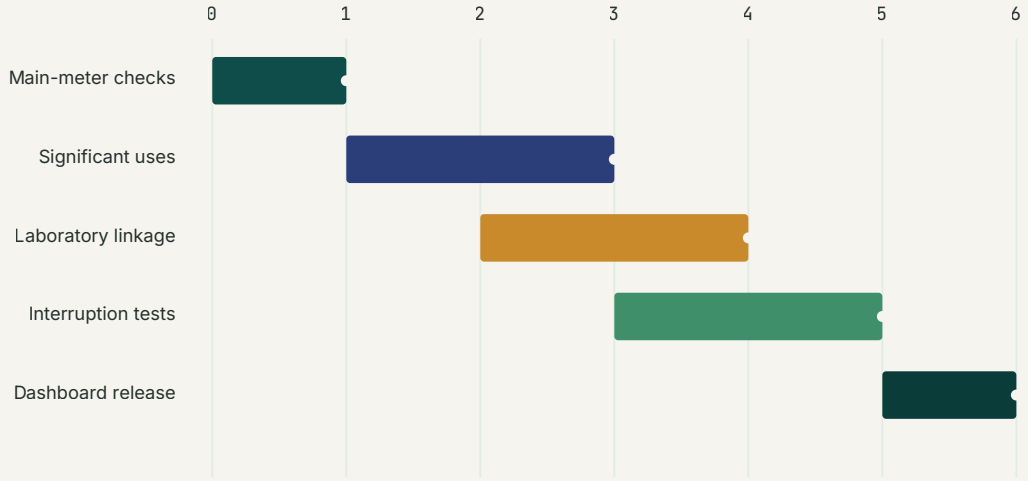
For the proposed resource record, capture the meter event time locally and record server receipt time separately. Keep a device identity, sequence reference, clock-quality flag and unit configuration with each observation. A reconnecting gateway should resend an unacknowledged event using its original identity. The receiver should recognise duplicates without dropping legitimate successive readings. Late data should enter the relevant production window, with the report revision visible. Receipt time alone is unsuitable for assigning a buffered observation to a batch that has already finished.

Power resilience needs to cover the observation chain. GFT recommends testing what the meter retains during power loss, what the gateway loses, whether a counter continues, and whether the clock restarts correctly. A surviving cloud database cannot reconstruct an unrecorded pulse. Local storage should be sized from the site's observed interruption pattern, reading frequency and a stated retention margin. Preserve missing intervals as missing even where a later cumulative reading recovers the period total. Knowing total consumption after recovery does not establish when each batch used it.

The illustrative sequence in **Exhibit 59**, p. 208 orders evidence tasks without promising calendar durations. Its axis contains assumed planning slots, not days or weeks. Main-meter checks precede extension to significant uses; laboratory linkage and interruption testing overlap; dashboard release follows review of the resulting records. The overlap is a design suggestion for commissioning dependencies, not a procurement schedule or a claim that staffing has been secured.

EXHIBIT 59 / ILLUSTRATIVE PLANNING SLOTS WITHOUT CALENDAR DURATION

Release follows reconciliation and interruption testing



ILLUSTRATIVE Assumed sequence only. Site readiness sets duration. Dashboard release requires accepted evidence from preceding tasks.

The manual fallback should use the same event definitions. GFT recommends controlled forms with meter identity, reading time, displayed unit, batch event, operator and correction reason. Where practicable, retain a dated image of the meter display as supporting evidence. On restoration, compare manual and automated readings over the overlap before importing either into the accepted account. An estimate bridging a missing interval should keep its method and uncertainty, with approval by the resource owner. It should not acquire measured status merely because someone typed it into the system.

Commissioning should include a deliberate restart and recovery exercise under a safe, authorised test arrangement. Verify event preservation, duplicate rejection, clock behaviour, backlog delivery and revised calculations after recovery. Keep the test record beside the capture configuration. GFT recommends withholding fine-grained batch comparisons when interruption leaves only an aggregate period total. The dashboard may still support a factory balance while showing batch allocation as unresolved. A coarser honest account remains useful; a false detailed account can direct action towards the wrong process.

13.5

Governance keeps the record comparable

Governance here means responsibility for resource definitions and corrections, not an enterprise-wide policy manual. Textile Exchange's August 2025 guidance calls for explicit understanding of LCA assumptions, methods and intended uses. ISO's energy-management overview supports systematic review through indicators and baselines. GFT translates those principles into a proposed resource measurement contract: the resource owner approves the boundary, the calculation and the permitted decision before the indicator enters routine review. [S23] [S18]

Every indicator should name its numerator, denominator, unit, included processes, reporting window, allocation basis and quality-release rule. The contract should also identify source records, treatment of missing data, normalisation variables, revision policy and accountable role. Retain approved versions with effective dates. A change in accepted-output policy, for example, requires review of historic comparability. A changed definition should not appear as process improvement merely because the familiar indicator name remains on the screen. Preserve a bridge between reporting versions where a defensible recalculation is possible.

GFT recommends making corrections additive and reviewable. An operator may propose a reading correction; utilities should assess a meter issue; the laboratory should approve a revised test result; production quality should authorise a changed release. A separate calculation owner should assess affected ratios and exports. This allocation of responsibilities describes proposed roles, not existing GFT staffing. Limit access to the actions a role needs, and retain both the original observation and the reason for its replacement. Shared credentials would defeat attribution and should be avoided in the proposed design.

Use the proposed daily review for actionable exceptions: missing reads, unresolved holds, abnormal rinse use and unusual correction cycles. Use the weekly review to reconcile utility branches, inspect recurring exceptions and decide which operating explanation to test. Use the monthly review to approve baseline changes, allocations and external reporting releases. Each meeting should end with a named role, a next action and evidence required for closure. The cadence is a GFT recommendation for this resource ledger, not proof that a performance system has already been deployed.

A closed exception should identify what changed in the process or record and why the evidence now supports closure. If a dyeing variance disappears only because an allocation coefficient changed, record that as a reporting correction. If a process intervention is tested, retain the comparable batch selection and quality outcomes. Do not merge administrative closure with verified reduction. This chapter defines the evidence record that an investment or scale decision will inspect; it does not replace the economic assessment or the gated operating roadmap in the neighbouring chapters.

For shared assets, GFT recommends reviewing the allocation driver whenever operating conditions change materially. Machine time, measured flow, thermal demand and accepted mass are different possible bases, each answering a different question. Select a basis that reflects the service consumed and preserve any known weakness. Unallocated residual should remain separate from a documented shared-service allocation. A reconciled total proves internal arithmetic consistency, not that the chosen driver accurately represents every batch's causal demand.

13.6

Product reporting needs a separate, explicit layer

The factory ledger is an input to product assessment. ISO 14040 covers life-cycle assessment and inventory studies within a broader methodological framework. The Commission's June 2025 announcement describes apparel and footwear footprint

rules spanning raw-material extraction, production, logistics, use and end of life. A batch resource account covers only its declared operations and cannot stand in for those wider stages. Its value is traceable primary data within a specified boundary. [S20] [S22]

GFT recommends a separate export record retaining the reporting purpose, product identity, batch links, allocated resource totals, coverage period and method version. Include the owned-operation boundary and the evidence status of partner data. Keep conversion factors, their source dates and geographic relevance available to the reviewer. A factory water ratio should remain a water-use observation until a selected impact method interprets it; it should not be relabelled as a complete product footprint. Similarly, electricity quantity and an emissions result should remain distinct fields with an inspectable calculation between them.

Supplier interfaces should request data at a useful boundary without pretending that unavailable detail exists. If a partner supplies an aggregate fabric figure, retain its output definition, period, included processes and assurance limitations. Do not blend that figure invisibly with measured garment-operation data. A product account can combine differently evidenced inputs only if it explains the allocation and uncertainty. Where supplier coverage remains incomplete, disclose the gap rather than backfill it with a favourable generic value and present the result as a measured supply-chain outcome.

Product passports introduce a further reporting purpose. The European Commission services' September 2024 FAQ explains that product-passport requirements depend on information requirements in applicable delegated acts. It is guidance, not authoritative legal interpretation or a current garment compliance opinion. The legal text could not be retrieved in this session. Before any external obligation statement, GFT recommends checking the then-applicable product rules, dates and access requirements with qualified advice. This chapter is an engineering framework, not investment, legal or tax advice. [S1301]

The export layer should publish approved information while preserving internal evidence. GFT recommends controlling access to recipes, supplier details and operational exceptions according to the reporting purpose. A customer-facing record need not expose every commercially sensitive process input to remain traceable to an authorised reviewer. Keep the internal source package and the released export linked by version. If a laboratory correction changes a released value, identify the affected exports and issue a recorded update rather than silently alter the internal ledger alone.

Product reporting should also keep purpose-specific calculation choices apart. A factory management allocation may support investigating machine losses, while a product study may require a different documented attribution. Retain each result with its own method and avoid overwriting the operating account to make the outputs agree. The resource spine should supply observations that can be reused transparently, not force every use case into a single indicator. This preserves the route back to production while allowing each receiving method to state its own assumptions.

13.7

Dashboards should distinguish fact, estimate and model

The dashboard should expose how a number was obtained and whether it is suitable for the decision beside it. GFT proposes measured, calculated, estimated and projected as operational evidence categories. Also retain independent validation flags for calibration, completeness, reconciliation, comparable output and approval. A measured value can be incomplete; a calculated value can be reproducible yet depend on estimated inputs. Approval records permission to use a value for a purpose, not a transformation of weak evidence into strong evidence.

The proposed control matrix in **Exhibit 60**, p. 211 uses a binary rule, not invented performance scores. Its illustrative value of 1 means that the named control must be resolved for that category before external release; 0 means that the control is applied through underlying inputs rather than directly to the displayed result. This distinction does not waive input checks. The categories are a GFT design convention, not an assessment scale prescribed by a cited standard.

EXHIBIT 60 / ILLUSTRATIVE RULE: 1 DIRECT CHECK, 0 INPUT-LEVEL CHECK

Evidence categories carry different release checks

	Instrument	Method	Coverage	Approval
Measured	1	1	1	1
Calculated	0	1	1	1
Estimated	0	1	1	1
Projected	0	1	1	1

Cell scale: 0 to 1

ILLUSTRATIVE Proposed binary controls, not maturity scores. All categories retain input lineage. Approval does not improve evidence quality.

Coverage needs a named denominator as well as a coloured status. GFT recommends displaying whether coverage describes expected meter intervals, production events, resource quantity or released output. These are different measures and should not share an unexplained completeness label. If a missing interval coincides with the largest processing event, a high count of otherwise complete intervals can still leave the relevant resource comparison weak. Report the known gap and its decision consequence; avoid converting a convenient record-count statistic into assurance about resource accuracy.

Before releasing the proposed dashboard, replay a small controlled evidence set with deliberately difficult events. Include a split batch, a correction route, a delayed release, a meter reset and a late duplicate observation. Define the expected accounting outcome before importing the records, then compare the displayed totals and evidence flags. The test should prove that material and resources are counted consistently and that unresolved data remain visible. It should also show that a revised report can be reproduced from retained inputs without altering the earlier observations.

A useful resource screen should show absolute quantity, accepted-unit intensity, reporting boundary, release coverage and unresolved balance together. GFT recommends offering a drill-down from an exception to the batch events, resource observations and quality decisions behind it. Do not average individual batch ratios without a justified weighting rule. Calculate an aggregate intensity from compatible resource totals divided by compatible accepted output, and show excluded or unresolved batches. A favourable average should not conceal held material or a deteriorating evidence boundary.

For the illustrative worked batch above, the rounded intensity of 60.42 litres per accepted kilogram is calculated from assumed inputs. It must therefore remain illustrative in this paper even though the proposed operational system could later calculate the same ratio from observations. A forecast of improvement would be projected and would need its assumptions and model version. A retrospectively corrected reading would revise the historical view with a visible audit trail. Display format should preserve those distinctions instead of presenting every value with the same apparent certainty.

Before predictive optimisation, GFT recommends testing whether comparable batch histories exist at all. Look for stable identifiers, consistent recipe versions, complete correction routes, aligned quality release and known missingness. A model should not learn an apparent saving from a meter replacement or from excluding failed batches. Any later predictive trial should retain the rule-based operating account as its comparator and keep recommendations separate from authorised process changes. The immediate deliverable is a usable evidence chain, not a promise of autonomous dyehouse control.

The resource owner should be able to answer an operating question with the record: which route changed, which observation supports that conclusion, which product passed release, and what remains uncertain? If those answers require rebuilding the account from disconnected files, the dashboard has not completed its job. A batch-

level spine earns its place when it shortens that investigation while preserving the evidence. It gives the subsequent improvement cycle a stable account against which a proposed reduction can be tested.

A meter becomes a management instrument when its number keeps the batch, the boundary and the decision together.

CHAPTER SOURCE NOTES

S18 International Organization for Standardization. 2018-08.

S24 Sustainable Apparel Coalition. 2022-12.

S20 International Organization for Standardization. 2006-07.

S37 Emerald Publishing Limited. 2019.

S33 ZDHC Foundation. 2024-09.

S25 World Bank. 2025-06-25.

S23 Textile Exchange. 2025-08-07.

S22 European Commission, Directorate-General for Environment. 2025-06-25.

S1301 European Commission services. 2024-09.

GREEN FUTURE TECH

LIMITED / HONG KONG SAR

14

A gated operating cycle turns baseline into verified reduction

GFT recommends a sequence of evidence gates, from a signed measurement contract to repeated operating proof, with scale conditional on resource, quality and environmental performance.

CHAPTER 14
DECISION TEST

GFT recommends a sequence of evidence gates, from a signed measurement contract to repeated operating proof, with scale conditional on resource, quality and environmental performance.

GFT recommends a gated operating cycle in which permission to proceed depends on evidence from the preceding stage. Define the measurement contract, establish a reconciled baseline, stabilise operating controls, test competing measures and verify persistence before releasing scale. Resource reduction should be demonstrated against accepted output within a declared boundary, with total demand, quality, effluent and cost retained beside the intensity result. This chapter specifies a proposed decision process. It reports no completed GFT pilot, achieved saving or approved investment.

The preceding chapters explain the resource mechanisms, investment account and batch record. The closing task is to turn them into instructions that a sponsor can approve and an operating team can follow. The sequence below is GFT's recommendation, informed by the energy-management framework described by ISO and by sector guidance on environmental controls. Its detailed gates, role assignments and acceptance records are proposed management arrangements, rather than requirements quoted from those sources. [S18] [S01]

14.1

Stage one fixes ownership and the measurement contract

The sponsor should appoint an accountable resource owner before requesting a reduction target. That owner assembles the measurement contract and obtains agreement from production, utilities, the laboratory, environmental management and finance. Each function should understand what it is approving. The contract should identify the process boundary, reporting period, resource inputs, accepted-output decision, exclusions, allocation rules and conditions under which comparisons cease to be valid. Approval authorises collection and interpretation under those rules; it does not certify an environmental outcome.

Owned operations and partnered processing should have separate schedules in the contract. A garment operation should not claim that lower purchased-fabric volume proves lower supplier dyehouse intensity. Conversely, a supplier improvement can inform a wider product account when its underlying boundary and release evidence are available. The Sustainable Apparel Coalition's technical paper describes separate energy and water reporting for fabric and finished-product facility types within an integrated facility. GFT recommends retaining that distinction when defining responsibilities across organisational boundaries as well. The technical paper is a historical design reference, not a declaration of current conformance. [S24]

The accepted-output rule must identify the release point, authorised decision maker and treatment of material awaiting inspection. Specify whether the physical basis is dry fabric mass, conditioned mass or pieces of a defined style. Reprocessing remains attached to its originating batch. Pending material should remain pending until the release decision is known; it should not disappear from the resource account. Where the reporting period closes earlier, retain a visible work-in-progress adjustment and prohibit a final intensity claim until its treatment is reconciled.

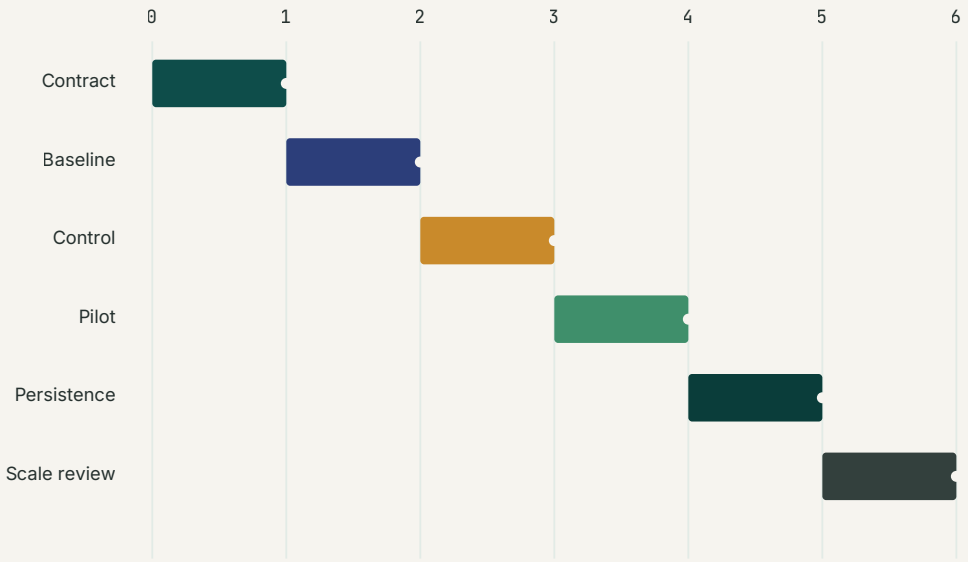
The contract should distinguish a product specification, an environmental limit and an internal investigation threshold. The laboratory owns the test method and release evidence for shade, fastness and other agreed attributes. The environmental function identifies applicable permissions, sampling points and release conditions with qualified site advisers. ZDHC's wastewater guidance includes wastewater and sludge testing and expressly states that its conformance is not a statement of legal compliance. It can inform a control schedule; it cannot substitute for the site's applicable obligations. [S33]

GFT recommends that any unsafe operating condition, unauthorised discharge, failed product release or missing critical measurement suspends the affected trial. A concern should trigger containment and investigation before the gate can reopen. Specify who can stop the activity, who protects material and samples, who records the event and who authorises restart. The person responsible for delivering a saving should not be the sole person deciding whether a failed release is acceptable.

The illustrative sequence in **Exhibit 61**, p. 216 uses readiness positions rather than calendar promises. Its equal-width intervals show order only. They neither estimate duration nor imply that difficult measurement work can be compressed to match a launch date.

EXHIBIT 61 / ILLUSTRATIVE READINESS POSITION, NOT ELAPSED TIME

Each stage starts after its entry evidence is accepted



ILLUSTRATIVE GFT planning model. Positions 0 to 6 indicate sequence only. Interval widths do not represent time, cost, staff effort or a promised completion date. Failed gates return to corrective work.

GFT NOTE

Approve the measurement contract before approving a target. Record an unresolved boundary, release rule or measurement gap as a condition that blocks the relevant claim. A larger dashboard cannot compensate for an undefined decision.

14.2

Stage two establishes a reconciled baseline

The baseline gate should establish whether the account is fit to support a trial. Utilities should verify meter identity, installation, units, read direction, timestamps and calibration or verification evidence. Production should reconcile accepted quantities to batch release and inventory movements. The laboratory should connect samples to the relevant operating interval. The resource owner then reviews the combined record, rather than approving separate spreadsheets whose reporting periods happen to share a label.

A baseline should cover the conditions the proposed measure is intended to serve. GFT recommends a coverage schedule by fabric family, shade class, batch loading, route, shift and relevant source-water condition. The schedule should identify represented conditions, missing conditions and unusual events. If a proposed project concerns a narrow route, a narrow baseline may be sufficient for that route. It should not silently become a baseline for the entire factory. There is no fixed baseline duration in this recommendation because representativeness must be demonstrated from the production record.

Reconciliation should occur separately for each physical account. For water, examine fresh intake, reuse transfers, wastewater, relevant evaporation and changes in stored volume. For electricity, compare supply and generation meters with significant uses and recorded losses. For fuel and chemicals, reconcile receipts, issues and stock movements before interpreting purchasing as consumption. Internal reuse transfers belong in the process balance but should not be added to fresh intake. These are proposed accounting checks, with tolerances set from site instrumentation and operating conditions.

Do not force a balance to close by distributing its unexplained difference across products. Keep a named residual, give it an owner and investigate its cause. A residual may reflect a timing mismatch, storage change, unmetered use or a faulty instrument; the record should preserve competing explanations until checked. Define the signed residual and its relative basis explicitly. A percentage based on incoming water answers a different question from a percentage based on allocated process water. The gate should examine both magnitude and plausibility.

The baseline pack should report absolute resource use and accepted-unit intensity together, with its method version and limitations. ISO's public description identifies energy performance indicators and energy baselines as tools for tracking improvement. GFT extends that management principle here to a linked water, chemistry and energy account, without claiming that the public description supplies the detailed textile measurement protocol. [S18]

A missing interval should receive an explicit treatment: exclude the affected comparison, retain a bounded estimate with its basis, or collect replacement evidence. GFT recommends showing coverage by resource and critical operating condition. A well-covered electricity account should not conceal an unmeasured wastewater boundary. Where uncertainty in the difference between baseline and trial could plausibly explain the apparent saving, the gate should authorise more measurement or a narrower claim rather than declare success.

The baseline review should also distinguish fixed demand from production-dependent demand. GFT recommends inspecting periods with different accepted throughput and asking which loads continue when output stops. If the comparison uses a simple resource-per-mass ratio despite a material fixed load, a change in utilisation can dominate the result. Retain the observed relationship and its applicable operating range. Do not introduce an elaborate adjustment model solely to obtain a favourable saving; compare its conclusions with a transparent simpler calculation and explain the difference.

Release the baseline only when the reviewer can reproduce a representative calculation from raw readings to accepted output and identify every adjustment. Freeze that version for the trial. Subsequent corrections require a reason, approval and a reproducible recalculation of affected results. A changed production route may justify a new baseline; it should not retrospectively erase a poor trial. Preserve the old account and explain why comparison with it has become unsuitable.

14.3

Stage three prioritises control before capital

GFT recommends beginning with preventable operating losses that can be investigated within existing safe procedures. The review should consider unwanted flows, idle demand, unnecessary holds, dosing errors, rinse endpoints, inconsistent moisture release, scheduling and rework. IFC guidance identifies controlled water flow, washing arrangements and reuse among sector measures. Those measures are investigation candidates; the source does not establish that any particular candidate is technically suitable or economically attractive at a GFT programme site. [S01]

Choose each trial from a documented loss mechanism. An entry might state that a valve appears to pass water during a non-production interval, identify the meter and observation supporting that concern, and propose a safe isolation check. Another might investigate whether a drying endpoint varies with loading. The hypothesis should explain the expected effect and the evidence that would refute it. A target selected solely because it looks attractive on an intensity chart is not an adequate trial design.

The paired comparison should retain product family, route, quality requirement and relevant operating conditions. Where possible, alternate or otherwise balance the trial sequence so a change in source water, operator or production schedule is less likely to be mistaken for a measure effect. Record unavoidable differences. If operating conditions cannot be matched, stratify the comparison or use a justified adjustment method agreed before results are reviewed. The point is to protect the decision from a convenient but misleading comparison.

Quality belongs inside the resource trial because correction consumes resources within the same production history. The right-first-time dyeing study opened for this chapter examines water hardness and dye concentration together, finding that both affect the colour result. GFT therefore recommends treating recipe and water-quality conditions as trial controls rather than assuming that a nominally unchanged machine setting creates a comparable batch. The study's particular recipe and result are not adopted as a universal operating setting. [S37]

A control trial should retain the starting settings, authorised change, meter readings, accepted quantity, analytical release, interventions and end state. Include cleaning, start-up, reprocessing and treatment where the boundary requires them. An operator's explanation of an abnormal event should stay beside the data. Deleting an inconvenient batch after seeing its result changes the question being tested. Exclusions should follow the agreed protocol and remain visible in the reported sample and coverage limitations.

At the exit review, classify the measure as repeatable operating control, promising but unresolved, unsuitable under tested conditions or inconclusive. An inconclusive trial is a useful result when it prevents unsupported scale. Successful control changes should enter an approved operating instruction with training and monitoring responsibilities. The controlled operating state then becomes the reference for the next capital comparison. Otherwise, an equipment proposal may be credited with savings already achieved through operating discipline.

14.4

Stage four tests competing technologies at pilot scale

A pilot should compare feasible ways of addressing the same identified load. For a water-intensive route, candidates might concern bath volume, preparation, washing or reuse. For a thermal load, they might concern moisture removal, heat recovery, operating temperature or heat supply. GFT recommends selecting candidates only after recording their required duty, source quality, capacity, space, maintenance and operating constraints. A supplier's percentage saving should be treated as a proposition to test against that duty, rather than a substitute for the baseline.

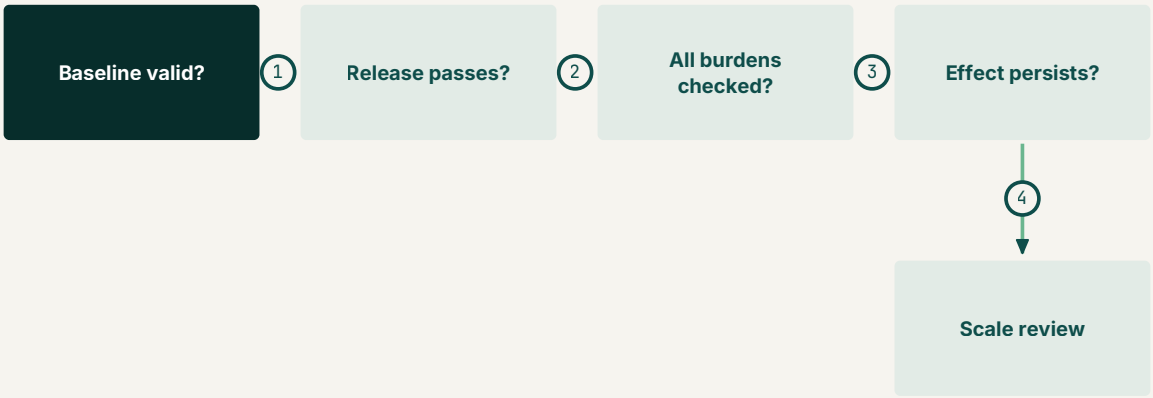
The reference case should be the stabilised process following operating control. Define precisely what the pilot changes and which supporting activities it requires. If a reuse option needs additional cleaning, treatment, pumping, concentrate handling or laboratory checks, those activities belong in its trial account. If a heat-recovery option depends on simultaneous source and sink availability, test the actual schedule. A favourable equipment demonstration cannot establish an annual factory result when its supporting conditions are absent from normal production.

The pilot protocol should specify product release, fastness, throughput, maintenance, resource demand, effluent and whole-cycle cost as joint acceptance conditions. Colour alone cannot establish fastness, and a low discharge volume cannot establish acceptable pollutant load. GFT recommends comparing concentration, flow and the relevant combined load where the sampling method supports it. ZDHC's distinction between wastewater and sludge pathways reinforces the need to keep residual management visible, while the applicable site requirements must be checked separately. [S33]

The gate logic in **Exhibit 62**, p. 220 is an illustrative management design. It makes a failed technical or evidence condition a reason to withhold scale. It does not assign scores that could allow a strong saving to cancel a failed safety or release condition.

EXHIBIT 62 / ILLUSTRATIVE DECISION SEQUENCE

A failed acceptance condition withholds scale



1. Pass
2. Pass
3. Pass
4. Pass

ILLUSTRATIVE [S01] [S33] [S37] GFT proposed gate logic, informed by environmental and quality references. The complete workflow is illustrative, not an observed implementation. Any failed condition returns to corrective work before re-entry.

Before the pilot starts, agree a safe fallback route and the conditions for returning to it. Retain enough material and operating information to diagnose a failed result where practical. Assign responsibility for isolating unsuitable reclaimed water, holding unapproved chemicals and preventing an experimental recipe from entering routine scheduling. These are proposed safeguards for the test boundary, not statements about controls already installed at any factory.

The illustrative calculation in **Exhibit 63**, p. 221 shows why acceptance and uncertainty change the decision even when intake visibly falls. Its invented values explain a method; they provide neither a factory benchmark nor a forecast.

WORKED EXAMPLE: ACCEPTED OUTPUT LIMITS THE SAVING CLAIM

Assume an illustrative matched-product baseline uses 100,000 litres of freshwater for 1,000 accepted kilograms, giving 100 L/kg. An illustrative pilot uses 85,000 litres for 950 accepted kilograms after all recorded reprocessing and release decisions, giving 85,000 / 950 = 89.47 L/kg. The intake falls by 15 percent, while accepted-unit intensity falls by about 10.53 percent. These are different comparisons, both calculated from the stated assumptions.

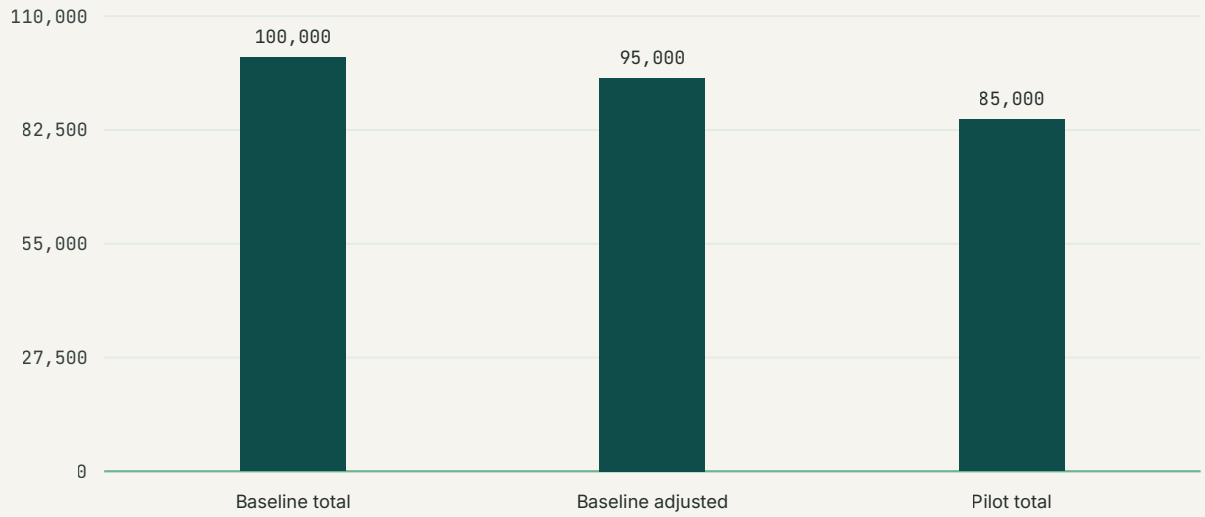
For the illustrative pilot's accepted volume, the baseline-equivalent intake is 950 kg multiplied by 100 L/kg = 95,000 litres. Comparable-volume avoidance is therefore 95,000 minus 85,000 = 10,000 litres. It is not the unadjusted 15,000-litre difference. This simple scaling assumes no material fixed water demand, identical product mix and otherwise comparable conditions. If those assumptions fail, use an agreed operating model or stratified comparison instead.

Assume, solely for an illustrative conservative bound, that the baseline-equivalent volume may vary by plus or minus 3,000 litres and the pilot volume by plus or minus 2,000 litres. Combining the adverse extremes gives avoidance from 5,000 to 15,000 litres: 92,000 minus 87,000 at the low end, and 98,000 minus 83,000 at the high end. These are assumed error bounds, not a statistical confidence interval. Shared or correlated errors would require a different treatment.

No illustrative electricity, chemical, effluent or cost values have been supplied. Those gate outcomes remain unknown. A positive water result authorises further investigation; it does not authorise a whole-cycle reduction claim or equipment purchase. The lower accepted quantity must also be explained before the process can be judged suitable for scale.

EXHIBIT 63 / ILLUSTRATIVE LITRES PER MATCHED REPORTING INTERVAL

Accepted-output adjustment narrows apparent water avoidance



ILLUSTRATIVE Invented teaching inputs: baseline 100000 L / 1000 accepted kg = 100 L/kg; pilot 85000 L / 950 accepted kg. At pilot output, baseline-equivalent demand = 950 × 100 = 95000 L. Comparable-volume avoidance is 10000 L, conditional on identical mix and negligible fixed demand.

The calculation does not establish why accepted output differs. GFT recommends investigating loading, rejected mass, work in progress and throughput before attributing the difference to the technology. Nor should the comparison silently change from freshwater intake to total circulated water. The pilot decision should state which resource changed, which conditions remain unresolved and what evidence would justify proceeding.

14.5

Stage five verifies persistence and releases scale decisions

Persistence means that a useful effect survives the conditions for which scale is proposed. GFT recommends repeating the leading measure across relevant fabrics, shades, shifts, loads and maintenance states, with the coverage plan defined before the verification campaign. A result obtained under a narrow range of conditions supports a narrow conclusion. Extension to an untested product route should be recorded as a new qualification task, not included in a broader claim by analogy.

The verifier should examine both performance and evidence quality. Reproduce calculations, check meter condition, trace accepted quantities and reconcile all excluded intervals. Examine whether an adjustment model is being applied outside the conditions used to establish it. Retain unfavourable trials and routine interruptions. Where possible, assign this review to someone who did not operate the trial or prepare its headline result. This is GFT's proposed separation of responsibilities, not a claim that external assurance has occurred.

The scale paper should distinguish observed physical effects, calculated comparable-condition savings, assumed future utilisation and supplier projections. Annualisation should state the eligible production volume and operating window. A measure qualified only for selected recipes should not be multiplied by total factory output. Finance should apply documented site prices and incremental operating costs to the verified resource account. Changed tariffs can affect value without changing physical performance; keep the resource and monetary conclusions separately reproducible.

GFT recommends testing utilisation, accepted yield, energy prices, maintenance burden, cleaning demand and persistence in the scale decision. Where evidence remains sparse, record a conditional scope and a further observation requirement. The reviewer should see what would make the project unattractive or technically unacceptable, rather than only the central case. No universal payback, carbon factor or borrowing case follows from this chapter. The process is an engineering decision framework, not investment, legal or tax advice.

The purchase specification should carry the qualified operating envelope into procurement. Include the duty, test boundary, guaranteed measurement method where agreed, product constraints, service requirements and commissioning evidence. A purchase decision is distinct from commissioning acceptance, and commissioning acceptance is distinct from sustained operating proof. Keep a scale hold point after commissioning, with responsibility for checking whether the installed system continues to deliver under ordinary production conditions.

Commissioning should preserve the separation between equipment functionality and process benefit. GFT recommends checking instrument installation, control sequences, safe shutdown, operator access, maintenance instructions and the agreed acceptance duty before testing savings. Record temporary bypasses and unfinished work. An installation that operates only with supplier intervention has not yet demonstrated routine operability. The final operating trial should identify the skills and service support that sustained performance requires, and the scale decision should account for their availability.

If performance drifts, compare current settings, product mix, meter health, source quality and maintenance history with the qualified envelope. An unexplained drift should suspend the affected claim and reopen investigation. Changing a dashboard target does not resolve a loss of proof. GFT recommends preserving the last valid result with its period and limitation, while reporting current performance separately. This keeps historical evidence useful without presenting it as a current operating achievement.

14.6

Named roles make the roadmap executable

The roadmap requires named role holders when a site adopts it, although this paper invents no personnel or organisational structure. GFT recommends that the sponsor approve resources and gate decisions; the resource owner maintain the integrated account; production own recipe execution, throughput and accepted quantity; utilities own meters and balances; the laboratory own analytical release; environmental management own the applicable environmental evidence; and finance own valuation assumptions. A small operation may combine roles, but it should retain a separate check on disputed results.

Every gate should have a compact decision record identifying the version reviewed, evidence accepted, unresolved exceptions, authorised scope, decision maker and next action. Use clear states such as collect more evidence, repeat under conditions, proceed within scope or stop. Avoid a general approval that leaves readers uncertain whether it concerns the measurement method, the trial or the capital release. The decision should identify what permission changes and what remains conditional.

GFT proposes a daily variance huddle, a weekly corrective-action review and a monthly gate meeting, adjusted to actual production and test readiness. The daily discussion should isolate an unexplained change and assign immediate checks. The weekly review should verify whether corrective actions closed their causes. The monthly meeting should approve trial entry, baseline revisions and scale decisions supported by complete evidence. These are proposed operating routines, not a statement that meetings or site results already exist.

Handover should include permission to maintain the control as well as permission to operate it. The proposed routine owner needs access to the approved settings, relevant evidence and a clear route for reporting drift. A replacement operator should be able to identify the current recipe and release rule without relying on the memory of

the trial team. When maintenance changes a component that affects measurement or process performance, the owner should identify the required recheck before restoring the saving claim.

An action should close when its evidence is accepted, rather than when somebody reports that work was attempted. A repaired leak needs a relevant readback; a changed dosing procedure needs demonstrated execution; a revised calculation needs a reproducible output. Set the form of closure evidence when assigning the action. Where the closure affects a published internal metric, retain the previous value and its correction reason so the operating record can explain what changed.

14.7

GFT's scorecard measures resources, quality and proof together

GFT recommends a scorecard with distinct physical, product and evidence views. The physical view contains absolute freshwater intake, discharge, electricity, fuel, delivered heat and chemical use, each with an accepted-unit ratio where meaningful. The product view contains colour release, fastness, right-first-time output, reprocessing and relevant moisture conditions. The evidence view contains coverage, reconciliation residuals, method versions and unresolved limitations. Keeping them adjacent permits a decision; combining them into a single score could conceal a failed condition.

The illustrative data dictionary in **Exhibit 64**, p. 224 summarises the physical account. Its units are proposed definitions, not observed values or targets. Keep fuel inputs and delivered heat distinct to avoid counting the same energy twice. Chemical mass should retain formulation identity and the active-content basis where available; a lower mass of a more concentrated formulation is not by itself proof of reduced chemical burden.

EXHIBIT 64 / ILLUSTRATIVE KPI DICTIONARY, WITH NO TARGETS

Each resource needs a total and a defined intensity

Account	Total / intensity	Proposed owner
Freshwater	L / L per A	Utilities
Discharge	L / L per A	Environment
Electricity	kWh / kWh per A	Utilities
Fuel input	MJ / MJ per A	Utilities
Delivered heat	MJ / MJ per A	Utilities
Formulated chemical	kg / kg per A	Production

ILLUSTRATIVE GFT recommended definitions. A denotes accepted kg for the specified route; garment operations may instead use accepted pieces with style retained. Fuel and delivered heat are separate accounts. No site performance values are assumed.

Supporting process measures should include liquor ratio, fixation where its method is valid, rinse endpoint, moisture release, reuse transferred to a defined duty and treatment electricity. Their purpose is diagnosis, not decoration. Record the measured object and denominator for each. Reuse recovery should distinguish the fraction of feed recovered from the fraction of total site demand displaced. Colour correction should distinguish a batch corrected during processing from material rejected after release testing. Otherwise, apparent trends may arise from changing definitions.

Targets should follow this scorecard rather than determine its definitions. GFT recommends setting a route-specific improvement objective only after the baseline and feasible controls are understood. Keep an environmental or product constraint as an acceptance condition, not as a negotiable average. The scorecard should show a missed target honestly even when the operating result is valid, and should mark an invalid result as unavailable even when its apparent value meets the target. Those distinctions prevent performance pressure from changing the evidence rules.

Evidence measures need similar discipline. Define coverage as the share of the intended resource quantity or operating interval supported by valid records, and state which basis is used. Track critical-condition coverage separately. Record meter residuals with sign, units and denominator; list overdue verification and unresolved baseline amendments. A high data-completeness ratio cannot override a failed critical instrument. The reviewer should be able to identify an invalid comparison directly from the scorecard.

The illustrative release checklist in **Exhibit 65**, p. 226 describes the first operating cycle's proposed outputs. Its counts are planning choices, not evidence of delivery. Each item requires an accepted content record, and none implies that a saving has already been achieved.

EXHIBIT 65 / ILLUSTRATIVE PLANNING OUTPUTS

The first cycle produces a baseline and testable decisions

1

Measurement contract

Approved scope and stop rules

1

Baseline pack

Reconciled account and limits

1

Trial record

All outcomes retained

1

Project register

Ranked by evidence and duty

ILLUSTRATIVE GFT proposed first-cycle checklist. Counts identify planning artefacts only. The trial record may contain failed or inconclusive tests; the project register may contain no scale-ready project.

14.8

The final recommendation is a disciplined scale path

For a new Cameroonian or African plant, GFT recommends carrying the resource ledger into design, equipment selection and supplier requests before operation begins. Specify accessible meter locations, retained laboratory identifiers, sampling access, maintenance responsibilities and information needed from partnered processors. Assess water supply, treatment and heat duties as site requirements. The design review should identify an unresolved resource constraint early enough to change the proposed route, rather than expecting an operating dashboard to correct it later.

For an existing plant, begin with a bounded route that has material resource demand, a clear release point and sufficient operating access to test a change. The initial objective should be an accepted baseline and a credible trial pipeline. Some candidates may

fail; others may need further instrumentation or a different product scope. The register should rank them by evidence, applicable duty, remaining dependencies and whole-cycle value. A long list of supplier proposals is not equivalent to a qualified pipeline.

Factory evidence should feed the programme's resource tools with its boundary, period, accepted-output basis and status intact. Do not relabel a site water-intensity result as a full product water footprint. Textile Exchange's integrity guidance stresses understanding assumptions, methods and intended use before using life-cycle data, and cautions against unsupported comparisons across studies. GFT recommends preserving the same discipline when a factory record becomes an input to wider impact reporting. [S23]

The next operational step is therefore a site-authorised, metered pilot on the actual product and supplier boundary, following approval of its measurement contract. This chapter supplies the proposed gates, not evidence that such a pilot has happened. Scale should follow a result that survives release checks, reconciliation, changed operating conditions and independent calculation review. Production makes the output; the measurement record determines which improvement claims the organisation can defend.

Scale the reduction that the operating record can still prove.

CHAPTER SOURCE NOTES

S18 International Organization for Standardization. 2018.

S01 International Finance Corporation, World Bank Group. 2007-04-30.

S24 Sustainable Apparel Coalition. 2022.

S33 ZDHC Foundation. 2024.

S37 Emerald Publishing Limited. 2019.

S23 Textile Exchange. 2025-08-07.

Provenance travels with the claim.

Available inherited records and all chapter-local source records are graded below. Identical source identities are consolidated without losing citation aliases. Missing annex references are excluded. Unrecorded dates are disclosed rather than invented.

R01 Inherited evidence R01 GRADE C

Business in Cameroon. Publication date unrecorded. businessincameroon.com

Cameroon seed-cotton production 2022-2024: 330,000 t (2022), 314,455 t (2023), about 340,000 t (2024).

Inherited source-text check; original source not independently re-opened for this edition.

R02 Inherited evidence R02 GRADE C

Fibre2Fashion; Business in Cameroon. Publication date unrecorded. fibre2fashion.com; businessincameroon.com

2025 seed-cotton projection above 350,000 t.

Inherited source-text check; original source not independently re-opened for this edition.

R03 Inherited evidence R03 GRADE C

SODECOTON. Publication date unrecorded. sodecoton.cm

Company profile: more than 220,000 cotton producers supported in northern Cameroon; nine ginning plants; two oil mills.

Inherited source-text check; original source not independently re-opened for this edition.

R04 Inherited evidence R04 GRADE C

Financial Fortune Media. Publication date unrecorded. financialfortunemedia.com

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Inherited source-text check; original source not independently re-opened for this edition.

R05 Inherited evidence R05 GRADE C

Ecofin Agency. Publication date unrecorded. ecofinagency.com

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Inherited source-text check; original source not independently re-opened for this edition.

R06 Inherited evidence R06 GRADE C

Cameroon Trade Hub. Publication date unrecorded. cameroontradehub.cm

About 95 percent of cotton fibre exported raw against 5 percent processed locally; industrialisation target of 50 percent local processing.

Inherited source-text check; original source not independently re-opened for this edition.

R07 Inherited evidence R07 GRADE C

Ecofin Agency. Publication date unrecorded. ecofinagency.com

SND30 restates the 50 percent local-processing target by 2030.

Inherited source-text check; original source not independently re-opened for this edition.

R08 Inherited evidence R08 GRADE C

Business in Cameroon. Publication date unrecorded. businessincameroon.com

Announced SODECOTON and CICAM merger to create a cotton-textile industrial pole targeted by 2030.

Inherited source-text check; original source not independently re-opened for this edition.

R09 Inherited evidence R09 GRADE C

Ecofin Agency. Publication date unrecorded. ecofinagency.com

Camtext SA integrated cotton-to-textile project, US$300 million (180 billion XAF); Panafritex and Arise with SODECOTON, CNPS and Marlo; 12 November 2025.

Inherited source-text check; original source not independently re-opened for this edition.

R10 Inherited evidence R10 GRADE C

Ecofin Agency. Publication date unrecorded. ecofinagency.com

Camtext SA: 12,000 t a year processed; about 12,000 jobs at the Dibamba hub and 3,000 at Garoua; return on investment near 11 years; optimal capacity around 2033.

Inherited source-text check; original source not independently re-opened for this edition.

R11 Inherited evidence R11 GRADE C

Business in Cameroon; MMI News. Publication date unrecorded. businessincameroon.com; mimimefoinfos.com

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R12 Inherited evidence R12 GRADE C

Business in Cameroon. Publication date unrecorded. businessincameroon.com

CICAM capacity utilisation, July 2023 report: Garoua 33.7 percent, CICAM 1 48.9 percent, CICAM 2 10.83 percent; underutilisation cost about CFAF 2 billion in 2020.

Inherited source-text check; original source not independently re-opened for this edition.

R13 Inherited evidence R13 GRADE C

Business in Cameroon; MMI News. Publication date unrecorded. businessincameroon.com; mimimefoinfos.com

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R14 Inherited evidence R14 GRADE C

WageIndicator. Publication date unrecorded. wageindicator.org

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R15 Inherited evidence R15 GRADE C

wage.is. Publication date unrecorded. wage.is/cameroon

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R16 Inherited evidence R16 GRADE C

WageIndicator. Publication date unrecorded. wageindicator.org

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R17 Inherited evidence R17 GRADE C

just-style. Publication date unrecorded. just-style.com

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R18 Inherited evidence R18 GRADE B

Congressional Research Service IF10149; AGOA (Wikipedia). Publication date unrecorded. congress.gov; en.wikipedia.org

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R23 Inherited evidence R23 GRADE C

MacMap; AfCFTA. Publication date unrecorded. macmap.org

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R24 Inherited evidence R24 GRADE C

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R25 Inherited evidence R25 GRADE C

Market.us. Publication date unrecorded. market.us

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R26 Inherited evidence R26 GRADE C

Statista. Publication date unrecorded. statista.com

Cameroon clothing and footwear spend about US$94.70 a person in 2024 and about 8.0 pieces a person; apparel eCommerce revenue US$20.32 million (2023) to US$33.61 million (2027) at 13.41 percent a year; user penetration 18.0 percent (2023) to 22.7 percent (2027).

Inherited source-text check; original source not independently re-opened for this edition.

R27 Inherited evidence R27 GRADE B

McKinsey, The State of Fashion 2025. Publication date unrecorded. mckinsey.com

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Inherited source-text check; original source not independently re-opened for this edition.

R28 Inherited evidence R28 GRADE C

DataIntelo. Publication date unrecorded. dataintelo.com

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R29 Inherited evidence R29 GRADE C

MDPI; industry inspection literature. Publication date unrecorded. mdpi.com

Manual defect inspection 60 to 70 percent accurate, missing 20 to 30 percent of defects; computer vision above 90 percent across more than 40 defect types; line-scan inspection up to 60 metres a minute.

Inherited source-text check; original source not independently re-opened for this edition.

R30 Inherited evidence R30 GRADE C

Design Journal (Taylor and Francis). Publication date unrecorded. tandfonline.com

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R31 Inherited evidence R31 GRADE C

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R32 Inherited evidence R32 GRADE C

Wise; XE. Publication date unrecorded. wise.com; xe.com

CFA franc to US dollar reference rates; franc pegged to the euro at 655.957. The GFT study's method note places the franc near 590 to 610 per US dollar across the 2023 study window and near 563 to 577 more recently, and treats currency conversions as estimates.

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c01-S01 Environmental, Health, and Safety Guidelines for Textile Manufacturing GRADE A

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c01-S03 Textile production water use and textile wastewaters: Literature Review GRADE B

VTT Technical Research Centre of Finland, Telaketju. 2024-04-16. https://cris.vtt.fi/ws/portalfiles/portal/102413557/2027caaf-tela-value_textilewastewaters_03-2024.pdf

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c01-S04 **Water and chemical consumption in the textile processing industry of Bangladesh** GRADE B

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MDPI, Textiles. 2022-09-28. https://www.mdpi.com/2673-7248/2/4/29

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c01-S08 **An analysis of industrial water use in Bangladesh with a focus on the textile and leather industries** GRADE B

2030 Water Resources Group, World Bank. 2015. https://documents1.worldbank.org/curated/en/099113024053527856/pdf/P181147-a915d380-0f92-4d66-b3ea-345e750e811e.pdf

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c01-S24 **Higg Facility Environmental Module (FEM) 4.0 Technical Paper** GRADE B

Sustainable Apparel Coalition. 2022. https://cascale.org/wp-content/uploads/2023/10/202212-SAC-Higg-Index-Higg-FEM-4-Technical-Paper-2.pdf

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c02-S01 Same source record as c01-S01.

c02-S02 **Best Available Techniques (BAT) Reference Document for the Textiles Industry** GRADE A

European Commission Joint Research Centre. 2023. https://bureau-industrial-transformation.jrc.ec.europa.eu/sites/default/files/2023-01/TXT_BREF_2023_for_publishing%20ISSN%201831-9424_final_1_revised.pdf

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c02-S03 Same source record as c01-S03.

c02-S04 Same source record as c01-S04.

c02-S05 Same source record as c01-S05.

c02-S07 **Reducing industrial water consumption in Tunisia** GRADE A

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c02-S09 The water footprint of cotton consumption: An assessment of the impact of worldwide consumption of cotton products on the water resources in the cotton producing countries GRADE B

Elsevier, Ecological Economics. 2006. https://www.waterfootprint.org/resources/multimediahub/Chapagain_et_al_2006_cotton_2.pdf

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c02-S16 Electrified Process Heating in Textile Wet-Processing Industry: A Techno-Economic Analysis for China, Japan, and Taiwan GRADE B

MDPI, Energies. 2022-11-25. https://www.mdpi.com/1996-1073/15/23/8939

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c02-S17 Improving Process Heating System Performance: A Sourcebook for Industry, Third Edition GRADE A

United States Department of Energy and Industrial Heating Equipment Association. 2015. https://stage.energy.gov/sites/prod/files/2016/04/f30/Improving%20Process%20Heating%20System%20Performance%20A%20Sourcebook%20for%20Industry%20Third%20Edition_0.pdf

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c02-S21 Regulation (EU) 2024/1781 of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products, amending Directive (EU) 2020/1828 and Regulation (EU) 2023/1542 and repealing Directive 2009/125/EC GRADE A

European Parliament and Council. 2024-06-13. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401781

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c02-S22 New EU rules for measuring environmental impact of clothes and shoes GRADE A

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c02-S24 Same source record as c01-S24.

c02-S25 Cameroon Power Sector Reform Program (P178136): Implementation Status and Results Report GRADE A

World Bank. 2025-06-25. https://documents1.worldbank.org/curated/en/099062525175018019/pdf/P178136-6edcadd2-3203-47e1-8e2b-f246281e1372.pdf

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Stable definitions make comparisons useful.

Accepted output

Kilograms, metres or pieces released to the next stage after the defined quality decision, used as the denominator for operational intensity.

Allocation

A documented rule for assigning shared water, energy or chemical use to products, processes or facilities.

Batch genealogy

The linked identity of a production batch, its input lots, recipe versions, machines, processing events, quality results and reprocessing.

Best Available Techniques

Techniques described in European BAT reference documents and conclusions as the basis for preventing or reducing industrial emissions and resource use.

Blue water

Surface water or groundwater withdrawn or consumed for irrigation, processing or another human use under the applicable water-accounting method.

Green water

Rainwater stored in soil and used by plants, distinguished from withdrawn blue water in water-footprint accounting.

Grey water footprint

An indicator of freshwater required to assimilate a pollutant load to a stated water-quality standard, not a metered factory water flow.

CIELAB

A colour-space system using coordinates such as lightness and chromatic components to express colour and calculate colour difference.

Chemical oxygen demand

A laboratory measure of oxygen required to oxidise material in a water sample, used as one indicator of effluent load.

Biochemical oxygen demand

A laboratory measure of oxygen consumed by biochemical processes in a water sample under stated test conditions.

Total dissolved solids

Dissolved inorganic and organic material in water, relevant to salts, reuse and concentrate management.

Total suspended solids

Suspended material retained by the specified filtration method in a water or wastewater sample.

Coefficient of performance

For a heat pump, useful thermal output divided by external energy input under stated source, sink and operating conditions.

Countercurrent washing

A washing arrangement in which fabric and wash water move in opposite directions so the freshest water contacts the cleanest fabric.

Data coverage

The share of the intended reporting boundary supported by valid measurements or documented estimates, including missing periods and meters.

Desizing

Removal of size applied to warp yarns before weaving, usually required before subsequent wet processing.

Digital product passport

A digital product-information system established within the ESPR framework, with detailed obligations determined through applicable product rules.

Dye exhaustion

The transfer of dye from the dyebath to the textile, calculated from initial and residual dyebath concentrations under a stated method.

Dye fixation

The proportion of dye durably bonded to the textile after unfixed dye has been removed, distinguished from exhaustion alone.

Dyebath reuse

Use of a residual dyebath in a later process after compatibility, residual chemistry and colour risks have been assessed.

Energy performance indicator

A measure or ratio used to monitor energy performance under an energy-management system.

Energy baseline

A documented quantitative reference against which later energy performance is compared, with relevant variables and boundary retained.

ESPR

The European Ecodesign for Sustainable Products Regulation, which establishes a framework for product requirements and digital product passports.

First-pass yield

The share of production that meets the defined quality requirement without repair, reprocessing or rejection at the first attempt.

Freshwater intake

Water entering the defined site or process boundary from municipal, surface, groundwater or other freshwater sources.

Gate-to-gate

An assessment boundary covering operations from entry to exit of a defined facility or production system, excluding upstream and downstream stages.

Heat pump

A device that uses external energy to transfer heat from a lower-temperature source to a higher-temperature sink.

ISO 14046

The international standard specifying principles, requirements and guidelines for water-footprint assessment based on life-cycle assessment.

Life-cycle assessment

A method for compiling and evaluating inputs, outputs and potential environmental impacts across a product system's defined life cycle.

Liquor ratio

The stated ratio of textile mass to processing-liquor volume for a machine or process, distinct from total site water per accepted unit.

Low-liquor dyeing

Dyeing with reduced processing-liquor volume relative to a defined conventional machine route, subject to quality and whole-cycle verification.

Measurement and verification

The disciplined use of boundaries, meters, baselines and calculations to quantify and check the result of an improvement measure.

Mercerisation

A sodium-hydroxide treatment of cotton that can change lustre, strength, absorbency and dye behaviour while adding chemical, rinse and heat duties.

MRSL

A manufacturing restricted substances list, which controls chemical inputs to production rather than only residues in the finished article.

Normalisation

Adjustment or stratification for relevant variables such as production volume, fabric, shade or operating conditions to improve comparability.

Overall equipment effectiveness

A production measure combining availability, performance and quality, used here alongside resource intensity rather than as its substitute.

Product Environmental Footprint

A European method for assessing environmental impacts across a product life cycle using defined category rules where applicable.

Pinch analysis

A thermal-integration method for identifying heat-recovery opportunities and utility targets from hot and cold process streams.

Process water

Water directly used in preparation, dyeing, printing, rinsing, finishing or other manufacturing operations, distinguished from unrelated site uses.

Reprocessing

A repeated or corrective operation such as re-dyeing, stripping, additional washing or repair after the first process fails release.

Reverse osmosis

A membrane separation process using pressure to produce permeate and a concentrated residual stream, with associated energy and maintenance demands.

Right-first-time

Achievement of the specified colour or product result without correction or another production cycle, measured under a defined release rule.

Scope 2

Indirect greenhouse-gas emissions from purchased or acquired electricity, steam, heat and cooling under GHG Protocol accounting.

Specific energy consumption

Energy used divided by production output for a stated energy and product boundary, usually requiring normalisation for comparison.

Stenter

A fabric-transport machine used for operations including drying, heat setting and finishing under controlled temperature and tension.

Water consumption

Water used within a boundary that is not returned to the same water system in the same period or form under the selected accounting definition.

Water footprint

A supply-chain or life-cycle indicator of freshwater use or impact, whose precise meaning depends on the method and boundary applied.

Water stress

The pressure on freshwater resources in a defined geography, commonly assessed through withdrawal relative to available resources after environmental-flow requirements.

Zero liquid discharge

A configured objective or system in which no liquid wastewater leaves the defined site boundary, requiring explicit treatment of salts, solids, energy and cost.

ZDHC

The organisation behind the Roadmap to Zero programme, including guidance on chemical inputs, wastewater, sludge and related conformance systems.

Follow the terms back to their context.

Page references point to occurrences in chapter prose. When a term does not occur in a chapter, its glossary definition is indexed.

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