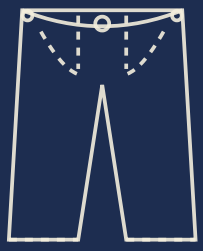
Industries of India

Denim Jeans

Fibre, Indigo, Uniform



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PART I - THE CLOTH

Chapter 1 - What a pair of jeans is

Pick up a pair of jeans and you are holding two things at once: a garment and a cloth. The garment is standardised almost to the point of invisibility - a waistband with belt loops, a fly, two front pockets, a small pocket nested inside the right one, two patch pockets behind, metal rivets at the corners that take the strain, orange or golden thread doubling every seam. The cloth is denim, and denim is defined with unusual precision for something so familiar: a warp-faced cotton twill in which the lengthwise threads are dyed indigo and the crosswise threads are left white [J3]. Every other property of the garment - its colour, its stiffness, the way it ages, the way it records its owner - follows from that one construction decision.

The word twill describes how the threads cross. In a plain weave, each weft thread passes over one warp thread and under the next, like a simple mat. In a twill, the weft floats over two or more warp threads before diving under, and the crossing point steps sideways by one thread on every row. The result is a diagonal rib running across the cloth, the wale you can see with the naked eye if you hold a jeans leg to the light. Because the warp threads are the ones that float on the face, the face of denim is dominated by the dyed yarn while the back shows mostly the pale weft. This is why jeans are blue outside and grey-white inside, and why a turned-up cuff shows a white edge.

It is also why denim wears the way it does: the dyed surface threads take the abrasion, and as they wear, the colour comes away in patterns that map exactly to the stresses of the body inside.

Denim is sold by weight, in ounces per square yard, and the number tells you roughly what the cloth is for. A shirting-weight denim might run five to eight ounces; the standard jeans cloth of the twentieth century sat around twelve to fourteen ounces; workwear and hobbyist cloth runs heavier, past sixteen ounces and up to thirty-two in the extreme Japanese reproductions. A square yard of fourteen-ounce denim contains a great deal of cotton, which is why a pair of jeans feels substantial in the hand in a way that almost no other everyday garment does. It is also why denim kept its reputation for toughness long after most of its wearers stopped needing tough clothes.

The anatomy of the garment itself is a fossil record. The little pocket inside the right front pocket was sized for a pocket watch, then for a Zippo lighter, and survives now holding nothing in particular. The rivets exist because a Reno tailor's customers kept tearing their pocket corners [J1]. The leather or cardboard patch at the back waistband began as a brand label - two horses failing to pull a pair of pants apart, in the case that set the convention [J2]. The orange thread was originally a simple contrast chosen to match the copper of the rivets. None of these features is load-bearing in the modern wardrobe, and all of them persist, because jeans are bought as much as an idea as as a garment.

That idea is worth naming at the start, because the whole of this book hangs on it. Denim is a material that improves under use in the eyes of its users. Nearly every other textile is judged best on the day it is sold. Denim is judged by what it becomes: the fades at the knees and thighs, the whiskering at the hips, the honeycombs behind the knees, the pale outline of a wallet or a phone carried for years in the same pocket. The industry sells this process in shortcut form as stone-washed, acid-washed and distressed product, and an entire finishing industry exists to simulate it. But the simulation only has value because the real process does. A pair of jeans is one of the few mass-produced objects whose final, most valued form is not the form

in which it leaves the factory. It is, in that sense, a collaboration between a mill and a life.

The chapters that follow take the garment apart in the way the Industries of India library takes everything apart: material first, then the science that shaped the material, then the people and machines that turned it into an industry, then the economies and dependencies that industry created. The cloth came before the jeans; the dye came before the cloth; the fibre came before the dye. But the place to start is the object itself, because almost everything in the story is already present, in embryo, in a single pair.

Consider the garment as a bill of materials. A standard five-pocket jean contains about a dozen pattern pieces of cloth, five to nine rivets depending on the pattern, a button and waistband tack, a zip or a stack of fly buttons, two pocket bags of lighter cotton or poly-cotton, several hundred metres of sewing thread in two or three colours, a waistband patch of leather or its paper-and-plastic substitute jacron, and a set of woven and printed labels. Each input is its own industry. The rivets and tack buttons come from metal-fastener specialists, the zips from a global duopoly of zip makers, the thread from industrial spinners, the labels from jacquard weaving firms. The jean is assembled from the outputs of at least six supply chains before the denim itself is even counted.

The fly is a small history of its own. The original fastening was a button fly, and it persists at the top of the market as a heritage feature, awkward and beloved. The zip - patented in its modern form in the 1910s and popularised in clothing from the 1930s - reached jeans late, because the button was part of the product's identity; when Levi Strauss finally offered a zip-fly 501 in 1954 it was as a separate model for Eastern customers thought to find buttons strange [J69]. Today the market splits cleanly: mass and women's jeans mostly zip, heritage and repro lines mostly button, and the choice reads as a statement about which century the wearer wants to belong to.

Finally, fit - the variable along which the modern market is sliced. Rise (where the waistband sits), leg (slim, straight, tapered, bootcut, wide) and fabric stretch define the product more than any structural change, and the cycle of fits is the industry's weather: flares in the

seventies, straight in the eighties, baggy in the nineties, skinny through the 2010s, wide again in the 2020s. Through every swing the chassis underneath - five pockets, rivets, twill, indigo - has not moved at all. The jean is a constant wearing a succession of silhouettes, which is precisely why each generation believes it has rediscovered it.

The book's method deserves a word before the material takes over. Each part follows the garment through one layer of its existence - its invention, its cloth, its factories, its markets, its meanings - and the layers are arranged so that the reader who wants only the story can read the odd-numbered arc and the reader who wants the industry can read the even one. Citations appear as bracketed tags, [J1] and so on, each resolving to a documented source in the companion volume, where every claim's evidence is listed with its read status - full text, excerpt, or located record. Where a number is a forecast rather than a measurement, the text says so. The rule throughout is the one the garment itself enforces: nothing in this book is true because it sounds true; it is true because it can be shown, the way a seam can be turned inside out and inspected.

A note on scope. This is a book about a product and the industry around it, written from the object outward: the jean first, the forces second. It is not a corporate history, though companies appear constantly; not a fashion history, though fashion arrives on schedule; not an environmental brief, though the environment is owed several chapters. It is, as nearly as one volume can be, the whole account - how a piece of hardware for labourers became the most successful garment ever made, what it costs the world to make two billion of them a year, and what the next century of indigo will require.

The sewing of the garment has its own bill of materials. A standard jean consumes several hundred metres of thread, and the thread is not one product but a system: a heavy, contrast-coloured topstitching thread - traditionally spun polyester or core-spun in the golden-orange shade the trade still calls "jeans gold" - for the visible seams, and a finer ecru thread for the invisible construction. The double-needle lap-felled seams that run down the outseam and yoke exist for the same reason as the rivets: a seam that can be abraded from both sides without bursting. Where seams cross - pocket corners, fly base,

belt-loop ends, the crotch - the bartack, a dense zigzag knot of stitching, does the reinforcing work that rivets cannot do invisibly. A quality jean carries a dozen or more bartacks, each placed where a generation of returned garments proved a failure point.

Count the industries inside a single pair and the jean becomes a small atlas of manufacturing. Cotton grower, ginner, spinner, dyer, weaver, finisher; rivet and button foundry; zip maker; thread spinner; label weaver; leather tannery or jacron maker; sewing factory; laundry; freight forwarder; retailer. Very few consumer objects priced for everyone compress so many trades into so little money. That compression - dozens of specialised suppliers coordinated into an object selling for the price of a restaurant meal - is the industry's real product, and most of this book is the story of how it is achieved and what it costs.

Chapter 2 - Two cities, two names

Denim and jeans are used today as if they were the same word. They began as the names of two different cities and two different cloths, and the history of how they converged is the first indication that this material has always been a commercial traveller.

The older word is jean. In Middle English, Gene or Jene was Genoa, the Italian port, and the cloth that carried the city's name was a fustian - a thick, strong, double-twilled fabric with a cotton weft, used for work clothes and ship's wear. Genoese fustian was traded across Europe; the first known English reference comes from a fifteenth-century manuscript by John Fortescue listing the goods coming out of Spain, where "geayne" appears among the oil, wine, salt, honey and wax [J3]. Genoese sailors and dockworkers wore trousers of the stuff, and the garment took the cloth's name. By the time the word reached America it meant simply a tough cotton trouser, and "a pair of jeans" - a pair of separate legs joined at the top, the same grammar as a pair of trousers - was established usage [J52].

Denim is French by accent and English by adoption. Serge de Nimes - serge, a twilled woollen cloth, from the city of Nimes in the south

of France - was clipped and anglicised over the course of the seventeenth and eighteenth centuries. The earliest known English appearance is in Edward Hatton's Merchant's Magazine of 1695, where a sample inventory for a would-be merchant lists "18 Serge Denims that cost 6 l. each" consigned to Aleppo [J3]. By 1771 a London bankruptcy auction advertised simply "denims" among the padua serges and flannels, and by 1777 a Bow Street notice describing a wanted forger's dress mentions "a pair of drab coloured cotton denim breeches" - the moment at which the word is visibly attached to cotton and to trousers rather than to woollen piece goods [J3].

Neither cloth was blue to begin with, and neither was what a modern buyer would recognise as jeans fabric. What the two names supplied was a geography of utility: cloth from ports and trading cities, made for people who worked. The third name in the family makes the same point from the other side of the world. Dungaree - still used in India and Britain for workwear, and in America for bib overalls - comes from Dongri, a dockside village near Bombay, whose coarse cotton cloth was exported to England from the seventeenth century. English speakers took the place-name for the fabric and the fabric for the garment, exactly as they had done with Genoa and Nimes. Three cities on two continents, each naming a tough cloth for working people, were folded into one garment's vocabulary.

There is even a painted record. In 2010 a curator working with seventeenth-century paintings attributed to an unknown northern Italian artist - three canvases dated to around 1655, now known under the name the Master of Denim - identified the figures' clothing as a blue twilled fabric matching the structure of denim, worn by ordinary people: a woman mending, children, a beggar [J8]. Whatever the precise fibre of those painted cloths, the exhibition that made the identification underlined the essential point: the association between this kind of cloth and this kind of wearer is far older than any brand. Long before it was American, the fabric of work was European, and before it was a fashion item it was a tool.

The modern meaning of both words was fixed in America in the second half of the nineteenth century, when a Bavarian immigrant's company in San Francisco began making riveted work pants from

denim and the garment's identity hardened into the form described in the previous chapter. The cities gave the words; the patent gave the object; the industry gave the object to everyone. That sequence - material, invention, industry - is the spine of this book.

The Genoese cloth tells us what early "jean" fabric was made of, and the answer is not quite cotton. Fustian was a mixed cloth - typically a linen warp with a cotton weft - woven thick and sheared or left ribbed, produced around Genoa and across northern Italy from the late Middle Ages and exported in quantity through the Mediterranean and beyond [J3]. Cotton itself was still a rare fibre in Europe, arriving from the Levant and India; the mixed construction was partly a way to stretch a precious weft with an ordinary warp. The garment trade that grew around the cloth - sailors' trousers in a busy port - fixed the association between the word and hard use at sea, centuries before the word meant anything American.

Nimes, meanwhile, was one of the textile towns of southern France, and its serge was wool - a twilled cloth of the kind the French made well and sold widely. The English clipped "serge de Nimes" first to "serge denim" and then to "denim", and then did what traders do: applied the name to whatever sturdy cloth fit the slot in their order books. By the late eighteenth century, as the Bow Street notice of 1777 shows, English "denim" could be cotton and could be breeches [J3]. The word had already made the journey from a place to a fabric to a garment type before it ever crossed the Atlantic.

In America the fabric arrived as work cloth and waited for its garment. Denim and its cousin duck - a plain-woven cotton canvas - clothed enslaved field workers before emancipation and industrial workers after it; when the California gold rush filled San Francisco with men who outwore their trousers, the dry-goods houses that supplied them, Levi Strauss & Co. among them, dealt in exactly these cloths [J2]. The jean was not invented from nothing in 1873. The fabric, the market and the need were all present; what was missing was the rivet.

The grammar is its own fossil. English says "a pair of jeans" for the same reason it says "a pair of scissors": the garment was once two separate leg coverings, hose joined at the top, and the plural stuck

long after the garment fused into one piece. "Pair of jeanes" appears in English records centuries before the garment reached America; the phrase carried the word across the Atlantic ready-made. Trade English keeps both words alive with distinct jobs to this day: in a mill's order book, denim is the cloth and jeans are the garments cut from it, and a "jeans" factory buys denim while a "denim" mill sells it. The two city names ended up on opposite sides of the counter.

The third name completed its own journey. Dungaree, from the Dongri dockside cloth, survives in Indian English as the everyday word for the garment itself - a shopper in Mumbai buys dungarees, not jeans - and in British and American workwear as the name of the bib overall. So the vocabulary of a single product still carries three ports on three seas: a Genoese cloth for sailors, a Nimes serge for traders, a Bombay dock cloth for labourers. Every wearer of jeans, in any language, speaks a small sentence of maritime trade history without knowing it.

Chapter 3 - The twill

Hold a piece of denim at arm's length and it looks blue. Hold it closer and it resolves into a field of diagonal lines, each line a ridge where the indigo warp yarns ride over the pale weft. That diagonal is the twill, and it is responsible for more of denim's behaviour than any other single feature.

Weaving is the organised crossing of two sets of threads. The warp runs the length of the cloth, held under tension on the loom; the weft is carried across, one pass at a time, by shuttle, projectile, rapier or a jet of air. The pattern in which they cross is the weave, and the weave determines the cloth's surface, strength, drape and thickness. Denim is almost always woven as a three-by-one twill: each weft thread passes under one warp thread and then the warp floats over three wefts, with the crossing point stepping one thread to the right on every successive weft. Because three-quarters of the surface is warp, and the warp is the dyed yarn, the face of the cloth reads as solid blue while remaining a two-colour fabric [J8].

The direction of the diagonal is a choice with real consequences. Most denim is right-hand twill, the wale running up to the right. Left-hand twill, woven with the diagonal reversed, produces a slightly softer surface, because the yarns - which are spun with a twist of their own - present themselves differently to abrasion. Some workwear cloth is woven as broken twill, in which the diagonal reverses direction at intervals and the rib breaks into a zigzag; the break stops the fabric from torquing, the tendency of a twilled leg seam to twist around the leg after washing. Anyone who has owned a cheap pair of jeans whose side seams drift toward the shin has met the problem broken twill was designed to solve.

Twill weaves in general are workhorse structures, and it is worth asking why this family of weaves, rather than plain weave or satin, carried the world's work clothes. The floats that create the diagonal rib let the yarns pack closer together, so a twill can carry more threads per inch than a plain weave of the same yarn; the cloth is denser, heavier and more abrasion-resistant for a given fibre. The floats also let the cloth drape - a twill bends where a plain weave of the same weight would board - and they hide soil, because dirt sits in the valleys of the rib rather than on a flat face. Every one of those properties mattered to the dockworkers of Genoa, the miners of California and the cowboys of the American West, and every one is still visible in the garment now.

The other half of the structure is the colour arrangement, and this is where denim parts company from other blue work cloths. In a piece-dyed fabric, the whole cloth is coloured after weaving. In denim, the warp is dyed before weaving and the weft is never dyed at all. The white weft is not an economy - though it is that too - it is a design. It lightens the cloth's inside against the skin, it gives the characteristic pale reverse, and above all it creates the contrast that makes fading visible: when a blue warp thread wears through or loses its dye, the white beneath shows. Denim's famous capacity to record wear is a direct product of weaving a dark warp against a white weft [J3].

Finally, weight. Cloth weights in ounces per square yard run from the lightest shirtings to cloth that stands up on its own. The standard that the industry quietly settled on for jeans, roughly twelve to fourteen ounces, is a compromise between durability and the

willingness of a human being to wear the cloth in summer. Heavier cloth lasts longer and fades with higher contrast; lighter cloth drapes and breathes. The modern market slices this axis into products - summer denim, heavyweight, raw - but the axis itself is as old as the fabric.

The weave is also where the cloth's technical specification lives. Mills describe a denim by its yarn counts - in the cotton system, the number of 840-yard hanks per pound, so a lower number is a thicker yarn - and by its thread densities, the ends (warp threads) and picks (weft passes) per inch. A classic fourteen-ounce denim might run warp yarns around Ne 7 to 10 and a weft a touch heavier, packed at sixty-some ends per inch; a shirt-weight denim uses much finer yarns and far more of them. From these three numbers - count, density, weight - the whole character of the cloth follows: its stiffness, its drape, the coarseness of its twill line, and the scale of the fades it will produce.

It helps to place denim among its neighbours. Duck or canvas is a plain weave - one over, one under - dense and flat, the cloth of tents, sneakers and work jackets; Levi Strauss sold brown duck pants alongside denim from the beginning, and duck lost the popularity contest precisely because its uniform surface wears flat and characterless where denim's rib records. Chino cloth is a fine, piece-dyed cotton twill, the khaki-trouser fabric - twill's drape without indigo's ageing. Gabardine is a steep, tight worsted twill built for raincoats. The family resemblance is real - all are answers to the same question of how to make cloth hard-wearing - but denim's specific answer, dyed warp against white weft in a three-by-one rib, is the only one that turns wear into ornament.

One more property deserves a paragraph, because it will matter when this book reaches stretch denim and recycling. The twill's diagonal gives the cloth a mechanical give on the bias - cut on the diagonal, denim stretches without any elastic fibre at all - while remaining stable along the grain. Pattern cutters have used that bias give at the yoke and waistband for a century to make a rigid cloth fit a moving body. Much of the later history of comfort denim is the story of trying to get by chemistry (elastane cores, recovery fibres) what the weave already offered by geometry.

The yarn's own twist adds a second, subtler geometry. Spun yarn is twisted in one of two directions, conventionally S or Z, and the twill's diagonal interacts with that twist: a right-hand twill woven from Z-twist yarn presents the fibres across the wale, sharpening the diagonal and wearing crisply, while the opposite combination bedims the line and softens the hand. Mills choose the pairing deliberately; the enthusiast market reads it. This is also why left-hand twill fades differently - the abrasion presents along the fibre rather than across it, and the cloth softens sooner. The famous leg-twist of a cheap jean is the same physics in failure mode: an unbalanced fabric in which the yarn's stored torque rotates the seam around the leg in the wash.

It is worth pausing on how much of the garment's later career is written into this chapter's facts. A warp-faced 3x1 twill in indigo-dyed yarn is: durable (dense floats), concealing (dirt sits in the rib), draping (floats bend), two-toned (blue face, white back) and capable of recording wear (ring-dyed surface over a white core). Every one of those properties will have a chapter of its own before this book is done - the wash floor exists to accelerate the last of them, the mills' art is to tune the first three, and the whole culture of raw denim is a cult of the fourth. Weave first; everything else follows.

Chapter 4 - The edge of the cloth

For most of denim's history, the cloth came off the loom with a finished edge, and that edge - the selvedge, from self-edge - was simply how woven cloth worked. In a shuttle loom, the same weft thread travels back and forth across the warp, turning around at each side and binding itself into a clean, unravellable border. Because a shuttle must be small enough to fly through the shed of the warp, shuttle looms weave narrow cloth, typically under a yard wide for the denim trades. The edge was a by-product of the machine, visible on the inside of every outseam and never seen by anyone who did not turn the garment inside out.

Shuttleless looms changed the geometry. From the middle of the twentieth century, projectile looms, rapier looms and air-jet looms took over the world's weaving because they were faster, wider and

cheaper to run. An air-jet loom blows each weft pick across the warp and cuts it at both ends; the cloth is more than twice as wide as shuttle-woven cloth, and its edges are fringed and must be tucked or stitched to hold. Mills chasing volume converted, and by the late twentieth century shuttle-woven denim was nearly extinct in the West. When Cone Mills closed its White Oak plant in Greensboro, North Carolina, at the end of 2017 - after 112 years of continuous production - the American trade press marked it as the end of the country's last selvedge denim mill [J14] [J15].

What happened next is a small parable about how industrial qualities become cultural ones. Denim enthusiasts in Japan and then everywhere else had come to prize old shuttle-loom cloth: its slight irregularities, its dense hand, and not least the coloured thread woven into the selvedge itself - red for some mills, which is why "redline" became slang for vintage Levi's. When the cloth disappeared from mass production, the edge became a signal. A turned cuff showing the selvedge ID announced that the wearer knew, or at least had paid for knowing. Narrow looms were recommissioned, vintage machines were shipped to Japan, and mills from Okayama to North Carolina found a market for making cloth slowly and badly by modern standards and beautifully by historical ones. The selvedge, an engineering by-product, became a premium feature worth real money per yard.

The episode matters beyond fashion because it shows how the denim market prices meaning. The shuttle loom did not come back because it makes objectively better cloth for digging ditches; nobody digs ditches in twenty-one-ounce selvedge jeans. It came back because the object it makes carries the story of how jeans used to be made, and a substantial global minority will pay to wear the story. That willingness - to buy the history along with the cloth - is what later chapters will meet again in vintage reproduction, in the cult of the Osaka Five, and in the resale market where worn jeans change hands for more than new ones.

The machines behind the two edges differ in kind, not just degree. A shuttle loom carries a bobbin of weft inside a wooden shuttle and throws it through the opening in the warp - the shed - hundreds of times a minute; the same thread turns at the edge and returns, which

is what makes the self-finished border. The Draper automatic loom, with its battery of reserve shuttles, made this cheap and continuous by the early twentieth century, and the denim trades ran on its descendants for decades. A modern air-jet loom, by contrast, measures a pick, blows it across with compressed air, and cuts it - several times faster and more than twice as wide, but every pick is a separate thread, so the edges fray and must be tucked or sealed.

Widths follow from the machine and fix the pattern-making. Shuttle-woven selvedge denim runs roughly 28 to 33 inches wide; a pair of jeans consumes well over a yard of it, and the outseam can be laid along the selvedge so no overlocking is needed - the origin of the turned-up-cuff display. Wide modern goods halve the waste but lose the edge, and the industry's two quality tiers can still be told apart at a glance by a turned cuff. The selvedge ID itself - a coloured yarn woven into the edge, red in the classic Cone cloth - began as a mill identification device and ended as a dating tool: collectors read the edge the way numismatists read a mint mark.

After White Oak's closure in 2017 the looms themselves became artefacts with afterlives [J14]. Some of the plant's Draper machines were bought and moved; a small North Carolina venture now weaves White Oak patterns on rescued looms for the heritage market, and Japanese mills that had kept their own shuttle fleets - Kuroki and its Okayama neighbours among them - found their slow machines suddenly fashionable. The selvedge story, complete in one generation, is how an industry forgets a technology, prices the memory of it, and then partially re-industrialises the memory.

The twill deserves its diagram in words. In a plain weave, each weft thread passes over and under alternate warps - the structure of bedsheets and shirting. In a twill, the weft floats over two or more warps before diving, and the float steps one warp sideways on each successive pass, drawing the diagonal wale the eye reads instantly on denim's face. The structure buys durability two ways: the floats let more yarn be packed into the cloth, and the stepped pattern distributes abrasion along the diagonals rather than concentrating it at every crossing [J8]. A 3x1 right-hand twill - three warps over, one under, the diagonal climbing to the right - became the denim

standard, with left-hand twill kept as a variant prized for a softer hand and a different fade.

The loom's own history shaped the cloth's character. Shuttle looms, which carried the weft across in a wooden shuttle, wove narrow widths - around 30 inches - with a finished edge, the self-edge or selvedge, that needed no overlocking. Projectile and air-jet looms, arriving in force after the 1960s, shot the weft across wide widths at several times the speed, leaving fringed edges to be cut and overlocked [J8]. The economics were irresistible - wider cloth, faster output, fewer stops - and the selvedge became a casualty of efficiency, surviving only where buyers would pay for the old weave's density and irregularity. Japan's shuttle-loom mills, kept alive by the vintage trade, later made the casualty into a luxury: the red-line selvedge ID, once merely the mill's edge-marker, is now read as a mark of authenticity, visible in the turned-up cuff [J16].

Weight completes the spec sheet. Denim runs from under ten ounces a square yard for shirting-weight cloth to beyond twenty for the so-called heavyweights of the enthusiast market; the standard jean sits around twelve to fourteen. Weight, weave, yarn and dye together define the cloth's personality - how it drapes, how it breaks in, how long it lives - and the mills' catalogues are essentially menus of these four dials. Everything the garment has been, it has been as a particular setting of those dials.

The selvedge carried information long before it carried status. Mills wove a coloured yarn into the edge as an identification mark - the selvedge ID - so that a roll of cloth in a cutting room could be traced to its maker at a glance; Cone's red line and its rivals' blue, green or yellow lines were the barcodes of the pre-computer mill. Collectors now read the same marks as provenance: the ID line, its colour, its pattern of dashes dates and sources a vintage garment as surely as a hallmark dates silver. An engineering convenience became a signature, then a certificate.

The physics of the edge explains the affection. Because the weft in a shuttle loom is one continuous thread, the cloth's edge is locked - every pick turns and binds - and the outseam sewn along it needs no overlocking stitch, no serging, no extra bulk. The result is a cleaner,

flatter seam and a cuff that shows a tidy bordered strip when turned. When the industry went wide and fast, it gave up that elegance for yield; when the connoisseurs objected, the industry discovered the elegance could be sold back at three times the price of what had been discarded. The selvedge market that resulted - narrow looms run slowly, cloth sold by the single-yard cut, cuffs turned to order in Tokyo and Amsterdam - is a working demonstration that in denim, the way a thing is made is itself a feature someone will pay for.

PART II - THE COLOUR

Chapter 5 - The oldest blue

Blue is the rarest colour in the ordinary landscape, and for most of human history it was the rarest colour in the dyer's vat. The earth offers red and yellow freely - ochres, madder, weld, saffron - but a strong, lasting blue must be coaxed out of a small group of plants that do not, at first inspection, look blue at all. The leaves of Indigofera tinctoria, a legume native to tropical Asia, are green. The woad plant of Europe, Isatis tinctoria, is greener still. Yet both carry, locked in their leaves as a colourless precursor, the same molecule: indigotin, C16H10N2O2, the dye that would eventually colour more working hours of human labour than any other [J5].

The trick that releases it is chemistry that ancient dyers practised for millennia without being able to name it. The precursor in the leaf is glucoside-bound and water-soluble; soaked in water, it hydrolyses and, in the presence of oxygen, couples into indigotin, which is not water-soluble at all. Indigo is a pigment, not a dye in the ordinary sense - it will not dissolve in water at any useful temperature, and it has no natural affinity for fibre. To get it onto cloth, dyers learned to run the vat in reverse: reduce the pigment in an alkaline, oxygen-free bath until it turns into its reduced form, leuco-indigo, which is soluble, pale yellow-green, and eager for oxygen. Cloth dipped in the vat comes out the colour of weak tea; minutes in the air, and the

leuco compound oxidises back to blue pigment, trapped mechanically inside the fibres it soaked into [J5]. Dyeing with indigo is therefore a cycle of chemical states - pigment to leuco to pigment - and every indigo-dyed object ever made, from an Egyptian mummy wrapping to this morning's jeans, passed through that same cycle.

Archaeology pushes the practice back thousands of years across unconnected civilisations. Indigo-bearing plants were worked in the Indus valley, in pharaonic Egypt, in pre-Columbian Peru, in West Africa and across East Asia. Each tradition solved the vat independently with local materials - fermentation vats fed with urine, bran or fruit sugars to keep the bath reduced and alkaline. The dye's fastness made it precious: properly vatted indigo does not bleed in water and barely fades in light, which is more than can be said for nearly every other natural colour. Where indigo travelled, it commanded prices to match, and it travelled far - along the same routes as pepper and silk, in cakes and bricks of dried pigment that served some economies almost as a currency.

Two features of this deep history matter for what follows. First, indigo was never merely decorative. A dye that survives sweat, sun and repeated washing is a working dye, and from the start it coloured the clothes of labour as readily as the robes of rank. Second, the chemistry that made it valuable also made it hard to industrialise. The vat is a living, temperamental system; traditional dyeing was skilled work with failure modes everywhere. Any industrial society that wanted blue cloth at scale would eventually want blue without the vat's moods - and wanting that, it would create first a plantation economy and then a chemical industry.

The precursor chemistry is worth one careful paragraph, because the whole industry sits on it. In the leaf, indigo's building block exists as indican, a glucoside: indoxyl bound to a sugar. Soaking and fermenting the leaves frees enzymes that split the sugar off; the liberated indoxyl, exposed to air, couples two molecules into one - indigotin, the blue pigment, which falls out of solution as a dark, insoluble solid. The dyer's vat then has to undo what the air just did. In the traditional fermentation vat, a soup of plant sugars, bran, or the ammonia of aged urine feeds microbes that strip oxygen from the bath; in that reducing, alkaline liquor, indigotin converts to leuco-

indigo, soluble and nearly colourless, ready to enter the fibre [J5]. Dyeing, vatting and oxidising are one chemical cycle run by three different actors: the plant, the microbe, and the air.

The living vat made indigo dyeing a skilled trade with its own priesthood in every culture that practised it. Japanese aizome workshops kept vats alive for years, feeding them sake and wood ash and reading the surface flowers - the bubbles and metallic film that told the master the bath's condition. West African dyers built pit vats and produced the deep, polished indigo cloths that signalled wealth across the Sahel. Indian dyers, working the plant's homeland, supplied both local traditions - bandhani tie-dye, ajrak block printing - and the export cakes that travelled the world. Each tradition found the same chemistry with different instruments, which is the surest sign that the chemistry, not the culture, was in charge.

And the colour carried its double meaning from the start. Indigo dyed the robes of West African elites and the smocks of French ouvriers - the bleu de travail that bequeathed the phrase "blue collar" - the uniforms of sailors and the festival cloth of peasants. Few dyes have ever served so far up and down the social ladder, and the reason is the same reason it ended up on jeans: it was the best-performing colour money could buy, and the market for performance is the whole market.

Europe's own blue was woad - Isatis tinctoria - the same indigotin molecule in a weaker plant, and the contest between woad and imported indigo was one of the early modern world's long trade wars. Woad regions - Thuringia, Languedoc, Tuscany - grew rich on the pastel-blue crop and defended it with everything they had: French and German edicts banned the import of the stronger Indian dye, and woad propagandists called indigo the devil's dye, corrosive to cloth and morals alike. The bans failed for the simplest of reasons: indigo contained many times the colour per pound of leaf, and dyers are economists before they are patriots. By the eighteenth century woad was a memory and indigo was the blue of Europe - imported, plantation-grown, and already entangled with empire.

The molecule itself stayed constant through every regime. Whether it came from Indigofera leaves steeped in Indian vats, woad balls

fermented in Thuringia, dyer's knotweed in Tokushima, or a BASF reactor in Ludwigshafen, what coloured the cloth was the same C16H10N2O2 - indigotin, an unusually stable, light-fast, pigmenting molecule that does not dissolve but clings. The history of blue is the history of who could deliver that molecule cheapest, and denim inherited the outcome: indigo won every round until the only remaining question was which industrial process supplied it.

Chapter 6 - Indigo country

For three centuries the world's indigo was grown where empires could make it grow, and the map of the dye reads like a map of colonial extraction. India - Indigofera's home, and the source of the word itself, indicum, from India - produced the finest and most concentrated indigo, and European trading companies fought for the trade from the sixteenth century onward. When the Spanish and Portuguese carried the plant to their American colonies, indigo plantations spread through Central America and the Caribbean. Britain's North American colonies joined in: in the 1740s, the South Carolina planter Eliza Lucas Pinckney, still in her teens and running her father's estates, made indigo grow and process reliably in the colony, and within a generation Carolina indigo was a staple export second only to rice [J58].

The cost of the blue was borne, as the cost of plantation commodities usually was, by the people compelled to produce it. Indigo processing was not only coerced but physically vile: leaves steeped in great vats, the liquor beaten to oxidise the dye, the sludge settled, strained, pressed into cakes and dried - stinking, fly-blown work in standing water. In Bengal, which became the centre of world production under British rule, the indigo system grew so extractive that it broke. Planters and their creditors forced peasant cultivators to plant indigo on their best land at advances that never cleared the debt. In 1859 the cultivators of Bengal rose in what became known as the Indigo Revolt, refusing to sow the crop, and the agitation - one of the largest peasant movements of the century - broke the back of indigo planting in the province [J58]. The dye moved on to Bihar and to factory-scale synthesis, but the revolt left a lesson that the

denim industry would be slow to learn: the colour on the cloth carries the conditions of the people who made it, whether the wearer knows it or not.

By the last quarter of the nineteenth century, natural indigo was a global commodity on an industrial scale: tens of thousands of tonnes a year, traded through London and Calcutta, feeding the mills of Europe and America. The product had been steadily improved - colonial "plantation science" systematised the vats and raised the dye content of the leaf [J58] - but the fundamentals were awkward. Yield per acre was low, quality swung with weather and soil, the cakes were bulky and adulteration was endemic. The market was, in other words, perfectly shaped for disruption: a huge, steady demand served by an expensive agricultural supply. All that was missing was a laboratory route to the same molecule.

That route would be found not in a colony but in a German university, and it would destroy the plantation industry within two decades. But the plantation era left the dye its cultural charge. Indigo blue was already the colour of work - of sailors' smocks and slaves' smocks alike, of the French bleu de travail that gave the language "blue-collar" - before a single pair of American jeans existed. When Levi Strauss eventually bought indigo-dyed cloth for his riveted pants, he was choosing the established colour of labour, and that choice was read, without a word being said, by everyone who saw the garment.

The trade's structure deserves a closer look, because it prefigures the denim supply chain three centuries early. Indigo was grown and crudely processed by cultivators, bought and graded by merchants, shipped as pressed cakes - the standard unit of the trade - and re-dissolved by dyers at destination. Quality was judged by the cake: the best grades were violet-blue, fine-textured, and light, and adulteration with earth and starch was common enough that buyers developed testing rituals. The East India companies built their indigo business on exactly this graded-commodity model, and by the eighteenth century indigo stood with sugar and cotton among the plantation staples that tied American land, African labour and European capital into one system.

South Carolina's entry shows how quickly the crop moved once its agronomy was solved. Eliza Lucas, managing her absent father's plantations from 1739, ran deliberate trials of indigo varieties and vat methods, sent seed and a skilled dye-maker through the planter network, and within a decade the colony was shipping hundreds of thousands of pounds of dye to London; after independence the trade shifted west and south with the cotton frontier [J58]. The lesson was not lost on contemporaries: indigo was a crop that could be transplanted wherever land, heat and compelled labour could be combined.

Bengal's crash a century later showed the same system's breaking strain. The 1859 revolt began when cultivators in the indigo districts simply refused to plant, and it spread fast enough to force an official Indigo Commission, whose 1860 hearings recorded the system in its own words: advances that could never be repaid, land diverted from food, coercion by planters' enforcers [J58]. Indigo planting in Bengal never recovered its hold, though the crop hung on in Bihar into the synthetic era. The revolt stands in this book as an early, violent proof that the people at the base of the colour's supply chain could read their own ledger - an ancestor of every later fight over what a cheap blue garment costs its makers.

The human structure of the trade deserves the same clarity as its chemistry. Indigo planting under colonial rule was rarely a free farmer's choice: in Bengal the ryots were bound to the planters' factories by advances and coercion, paid for leaf at prices set by the men who bought it, and pressed to plant indigo on land they needed for rice. The resentment detonated in 1859-60 in the indigo disturbances - a rolling strike and revolt across the Bengal indigo districts that emptied the factories, filled the courts, and produced both a government commission and a famous play, Nil Darpan, the "mirror of indigo" [J53]. The crop never fully recovered its Bengal heartland; the trade shifted, thinned, and then met the synthetic that ended it.

That double nature - indigo as at once a craft material of great beauty and an instrument of extraction - is the reason this chapter precedes the factory rather than following it. The blue on a modern pair of jeans carries both histories, and the industry's later pattern was set

here: a commodity whose glamour at the counter was built on discipline in the field, and whose true cost was paid furthest from the person wearing it. The geography changes by the century - Bengal to Gujarat to the synthetic works - but the shape of the bargain has proved durable.

Chapter 7 - The chemist's blue

Adolf von Baeyer began attacking the indigo problem in 1865, in his Munich laboratory, at a time when organic chemistry was just learning to build molecules rather than merely analyse them. Indigo was the obvious target: expensive, agriculturally constrained, and chemically well-behaved enough to hope for a synthesis. Baeyer achieved a first laboratory synthesis from isatin in 1878 and a second, from 2-nitrobenzaldehyde, in 1880, and in 1883 he finally established the molecule's structure [J5]. He would win the Nobel Prize in 1905 in large part for this body of work. But a laboratory synthesis and an industrial process are different species of achievement, and Baeyer's routes were hopeless for manufacture - the starting materials cost more than the indigo they produced.

The industrial prize went to Badische Anilin- und Soda-Fabrik - BASF - of Ludwigshafen, working with Baeyer's academic successors and the chemists Karl Heumann and Johannes Pfleger, who found routes from cheap coal-tar feedstocks: from naphthalene via phthalic anhydride, and from aniline. The development consumed seventeen years and some eighteen million gold marks, more than the company's share capital at the time - one of the largest single research bets of the nineteenth century [J4]. In 1897 BASF launched "Indigo Pure BASF", a synthetic product chemically identical to the plant dye, at a consistent purity no agricultural cake could match and at a price that fell as production scaled [J4] [J5].

The effect on the old industry was swift and total. At the peak of the plantation trade, well over a million acres were planted to indigo; within twenty years of the BASF launch, world demand for natural indigo had collapsed to a fraction of its former size, and the colonial indigo districts never recovered. Economists still cite the episode as

the classic case of synthetic chemistry annihilating an agricultural commodity - the same pattern, at the same moment, as synthetic alizarin did to the madder fields that supplied red dye [J58]. What is less often noticed is where the synthetic dye's volume went. Indigo did not shrink into a speciality. BASF's own corporate history records the dye's second life: after the First World War it settled into steady industrial use, and then "indigo undergoes a renaissance in the mid-1960s, when blue jeans become a cult item for an entire generation," becoming a pillar of the company's dye business for the second time [J4].

The molecule had not changed. What changed was the scale of the garment it coloured. By the late twentieth century, synthetic indigo was being produced in the tens of thousands of tonnes per year, the overwhelming majority of it for one application: dyeing the warp yarn of denim. A dye invented for royalty's robes, fought over by empires, synthesised at ruinous research cost by the founders of the modern chemical industry, ended as a bulk commodity whose destiny is measured in pairs of trousers. And the chemistry that Baeyer elucidated still runs, unchanged, in every denim dyehouse on earth - which is where the next chapter goes.

The synthetic dye was one product of a larger event: the birth of industrial chemistry itself. When William Perkin stumbled on mauve in 1856 while trying to make quinine from coal tar, he opened the aniline-dye industry; German firms - BASF, Hoechst, Bayer - turned the trick into a national sector, systematically converting coal-tar aromatics into colours, and later into explosives, pharmaceuticals and fertiliser. Indigo was the industry's Everest: the highest-value natural colour still unsynthesised, with a market measured in thousands of tonnes. The scale of BASF's bet - seventeen years, eighteen million gold marks, more than the company's share capital - tells you what the prize was worth [J4].

The winning routes deserve a sentence of chemistry, because they fixed the feedstock for the next hundred and thirty years. Karl Heumann found paths to indigo from naphthalene, via phthalic anhydride, and from aniline, via phenylglycine; both start in the coal-tar (later petrochemical) stream and both remain, in modernised form, the basis of essentially all synthetic indigo made today [J5].

That continuity is remarkable: the dye in a 2026 pair of jeans is produced by a process whose chemistry was settled in the 1890s, one of the oldest continuously operating synthesis routes in the chemical industry.

The displacement that followed is still the textbook case. Natural indigo's cultivation collapsed from well over a million acres worldwide to a rump within about twenty years of 1897, and the pattern - laboratory product annihilates agricultural commodity - has been cited ever since, from synthetic rubber to vanillin [J58]. But the second half of the BASF story is the part this book cares about: the synthetic dye did not shrink to fill its old niche, it grew into a new one. Cheap, consistent indigo in unlimited quantity is what allowed denim to become a global uniform rather than a regional work cloth. The plantation dye could never have coloured two billion pairs a year; the flask could [J4].

The commercial fight at the turn of the century was fierce and brief. Natural indigo's defenders - planters, merchants, and some dye-masters - attacked the synthetic as fugitive and inferior, and BASF answered in the only way that settles such arguments: by paying for side-by-side dyeings and publishing the results. The synthetic won on consistency. A natural dye varied by soil, season and vat-keeper; the factory product arrived as a standard powder of guaranteed strength, and a dyehouse could write recipes around it. In an industry converting from craft to production line, the standard powder was destiny [J4].

The price history completes the story. Synthetic indigo entered at a premium, then fell and kept falling as routes improved and competitors - Hoechst and the other German works, later Swiss and American and eventually Chinese producers - piled in. Within a generation the price of indigotin had dropped by an order of magnitude, and the blue that had once been worth its weight in colonial revenue became one of the cheaper items in a dyehouse inventory. Every later denim boom, from the waist overall to the two-billion-pair market, stands on that collapse: the jean is blue because blue became nearly free [J4].

Chapter 8 - The vat, industrialised

Modern denim dyeing runs the ancient cycle on a production line. Synthetic indigo arrives at the mill as a fine powder or paste; it is insoluble, useless until reduced. The dyehouse's reducing agent of choice for over a century has been sodium dithionite - hydrosulfite, in the trade's older vocabulary - in a hot caustic-soda bath. In the absence of oxygen, the dithionite strips the indigo molecule of its carbonyl oxygens' grip and converts it to the soluble leuco form; the bath turns the yellow-green of weak urine, and in that state the dye can finally enter a fibre [J5].

The engineering problem is that a single dip cannot carry enough dye. Indigo's affinity for cotton is modest, and the target shade - the deep navy of a new pair of jeans - requires far more pigment than one bath deposits. So the warp is not dipped once but many times: the yarn sheet or rope passes through a series of vats, typically six to twelve in sequence, with a passage through open air between each. In the air, the leuco-indigo in the yarn oxidises back to blue pigment; in the next vat, another layer of leuco is laid down and oxidised in turn. The shade is built up in skins, like coats of varnish. A dye range for denim is therefore a long machine - feed creels, a battery of vats with squeeze rollers, sky-high airing galleries where the yarn travels slowly enough to oxidise, and a final wash and dry - and its tempo is set by chemistry: the yarn cannot be hurried through its airing, because oxygen takes the time it takes.

The consequence that defines denim is where the dye ends up. Each dip deposits a thin shell of pigment on and just beneath the yarn's surface, but the penetration is shallow; the core of the yarn stays white. The trade calls this ring dyeing, and it is not a flaw to be engineered away but the property on which the entire product depends [J8]. A ring-dyed yarn is a white yarn wearing a thin blue coat, and abrasion removes the coat first. That is why jeans fade where they rub - knees, thighs, seat, the ridges of the twill itself - and why the fades are high-contrast: a small amount of wear produces a large change in colour. No other mass-market textile is dyed to be destroyed gracefully in exactly this way.

The vat's chemistry has costs that later chapters will revisit. Sodium dithionite decomposes into sulphite and sulphate loads in the effluent; caustic soda drives the pH of the waste stream high; and the pigment that does not fix - and much does not, since indigo fixes mechanically rather than chemically - washes out as a blue suspended load that stains rivers in production towns around the world. The dye itself is fairly benign as synthetic dyes go, but the process around it is not. Every alternative the industry has developed - pre-reduced indigo, electrochemical reduction, foam application, plant and microbial indigo - is an attempt to keep the molecule while escaping the vat [J18] [J28] [J29].

For now, note the essential shape: the blue of a billion garments is applied as a sequence of controlled chemical failures, dip and oxidise, dip and oxidise, until the yarn carries just enough pigment to fade beautifully for years. The industry did not set out to design a cloth that records its owner's life. It set out to make deep blue cotton fast and cheap, and the recording property came free.

Sodium dithionite, the modern vat's workhorse, earns a paragraph of its own. Na2S2O4 is a powerful, convenient, somewhat treacherous reducing agent: it decomposes in water, faster in heat and air, into sulphite, sulphate and thiosulphate, so the dyehouse feeds it continuously and pays for it twice - once in the reagent and again in the dissolved-solids load of its effluent. The bath runs hot, alkaline (caustic soda to pH 11 or beyond), and oxygen-free; operators watch vat potential the way their predecessors watched the flowers on a fermentation vat. The chemistry is Baeyer's, the reagent is twentieth-century electrochemistry's, and the control problem is eternal: hold a reactive bath at the edge of stability, hour after hour, kilometre after kilometre of yarn [J5].

The machinery built around that bath is among the most distinctive in the textile industry. A denim dye range stretches the length of a factory hall: creels feeding hundreds of yarn ends, a battery of five to twelve vats in series, squeeze rollers between them, and after each vat the long skyer - rollers carrying the yarn high and slow through the air so the leuco dye can oxidise back to blue before the next dip. The shade is dialled by dip count, bath concentration and speed, and the range runs continuously for days. Stopping is expensive;

consistency is the whole product. When buyers speak of a mill's "hand" or shade signature, they are describing, more than anything, the behaviour of its range [J8].

What leaves the range carries the ledger that Part VIII will audit. Indigo fixation is partial by design and by physics - the pigment sits in and on the yarn's surface, and a significant fraction of what was vatted never fixes at all, washing out in the range's final rinses as intensely coloured suspended solids. Add the dithionite decomposition products, the caustic load, and the starch size applied to the dyed warp for weaving, and the dye range emerges as the largest single source of chemical oxygen demand and colour in the denim chain. Every innovation in Part IX - foam, electrochemistry, pre-reduced and bio indigo - is aimed at some term of this equation [J18] [J29].

The chemistry has its own housekeeping problems, and they shape the factory. An indigo bath is a reduced, alkaline solution that wants nothing so much as to revert: oxygen in the air, oxygen in the yarn, temperature swings and time all push the leuco-indigo back to pigment, so the range fights a continuous holding action - dosing sodium dithionite to keep the bath reduced, holding pH with caustic soda, metering temperature and dip times. The dyer's art, industrialised, is to keep a chemically unstable system steady across kilometres of yarn travelling at tens of metres a minute [J29]. When the dosing drifts, the shade drifts, and shade variation - once accepted as the character of hand-dyed cloth - is now a quality defect sorted out at inspection.

The range's appetite is the ledger's first line. Each dip is a bath of water, dye, alkali and reducing agent; a twelve-dip line holds twelve; the yarn carries liquor from bath to bath and out the far end to the wash boxes. Multiply by the hundreds of millions of metres a large mill dyes each year and the water, salt and dithionite accounts become the mill's largest variable costs after cotton itself. Part IX's machines - foam, pre-reduced dye, nitrogen blankets - are all aimed at this paragraph's arithmetic [J21] [J28].

Chapter 9 - Rope and sheet

Between the bale of dye and the loom, a mill makes one of two choices about how to present the warp to the vats, and the choice is old enough, and argued enough, to have factions.

In slasher dyeing - sheet dyeing - the warp yarns are laid out as a flat sheet, hundreds of ends side by side, and run through the vats as a continuous ribbon of yarn. The machinery is direct and the throughput high, but a wide sheet of wet yarn in a hot alkaline bath is prone to stretch, to uneven tension and to side-to-centre shade variation; the dye must be coaxed to levelness across the full width. In rope dyeing, several hundred ends are twisted loosely together into ropes, and the ropes - a dozen or more at once - pass through the vats like hanks of spaghetti. The yarns inside a rope are protected from stretch and from the squeeze rollers, so the dye penetration is more controlled; after dyeing, the ropes are laboriously opened and re-beamed into a weaver's warp. Rope dyeing is slower, longer and more expensive, and it is generally credited with the deeper, more ring-defined dyeing that the premium end of the market prefers [J8].

Neither route is a curiosity: a modern denim plant runs its dye range continuously, and the range is the heart of the factory and the source of most of its effluent. Variations multiply around the basic process. Sulphur dyes, cheaper and with different fastness, are used alone for black and brown denims and as "bottoms" and "tops" layered with indigo - a sulphur base under indigo deepens the shade cheaply and changes the fade. Pre-reduced indigo, supplied already in leuco form, cuts the dyehouse's handling of reducing agents. And a small, determined fringe of the industry has always kept natural indigo in production for customers who will pay for it; in 2017 Cone Denim, working with the Tennessee growers of Stony Creek Colors, put a natural-indigo selvedge denim into commercial production - plant dye, grown on American farms, running on industrial equipment [J30].

What a buyer is purchasing, underneath the brand, is largely the output of this machine: the depth of shade, the ring definition, the cast - indigo is never a neutral blue; it runs red-cast or green-cast depending on dye lots and auxiliaries - and the way the cloth will age. Mills guard their dyeing recipes the way food companies guard flavour formulations, because in the end denim is a commodity cloth

differentiated almost entirely by how its one dye was applied. Two fabrics with the same cotton, the same weave and the same weight can be told apart across a room by the blue, and the blue is the range.

Between the two great methods sits a third, older compromise: loop dyeing, in which a single rope circulates repeatedly through one vat rather than passing through a series. It is slow and nearly extinct, kept alive by a handful of specialist mills - the premium market again - because repeated gentle passage lays down exceptionally ring-defined dyeing. The three methods map cleanly onto the industry's tiers: sheet for volume, rope for quality, loop for the boutique edge, and all three execute the same dip-and-oxidise chemistry that Part II described [J8].

The dyer's other tool is the sulphur family. Sulphur dyes - cheap, muted, and fixed by a similar reduction chemistry - serve denim in three roles: alone, for the blacks, browns and olives of the non-indigo market; as "bottoms", a sulphur base applied before indigo to cheapen and deepen the shade; and as "tops", cast over indigo for gunmetal and black-over-blue effects that fade differently from pure indigo. The bottomed shades are why two indigo jeans of the same nominal colour can age on different paths, and why the trade's shade cards carry names like "deep", "dark sulphur bottom" and "green cast" as distinct products rather than accidents.

After dyeing comes the least visible step in the whole chain: sizing. The dyed warp - its surface hairs raised, its strength partly spent - is coated with starch or synthetic size to survive the violence of weaving, then beamed for the loom. Size is why loomstate denim feels boardy, why the first wash of a raw jean clouds the water, and why desizing is the first act of both the finisher and the laundry. A jean's chemistry is thus layered in exact industrial order: fibre, spin, dye, size, weave, finish, wash - and the owner adds the final layer, wear, which undoes them selectively in the reverse order.

The choice between rope and slasher is made on capital and product, not sentiment. A rope-dyeing range costs more, runs slower, and needs the warped ends opened and re-beamed after dyeing - an extra machine, an extra step, extra hands - but it delivers the deep, ringed shades and the fade character the market calls authentic. Slasher

dyeing dyes the yarn as a flat sheet straight from the warper's beam: faster, cheaper, one less handling stage, but the sheet's threads pack flat against each other and take the dye more evenly, giving a flatter shade and a flatter fade. Premium denim is nearly all rope-dyed; the volume market mixes both, and the two ranges can stand side by side in the same mill, feeding different price points from the same bales.

After dyeing, the yarn still must survive the loom, and that is sizing's job: the warp is run through a bath of starch or synthetic size that glues the fibres' fuzz to the yarn's body and gives it the abrasion resistance to withstand thousands of shed openings. Size is a loan, not a gift - it must be washed out of the finished cloth, and desizing is one of the wet processing chain's routine loads. Every stage hands a problem to the next: the dyer hands ring-dyed yarn to the weaver, the weaver hands sized, harsh loomstate to the finisher, the finisher hands stable cloth to the cutter, and the laundry, at the end of the line, undoes what it must to make the garment look old.

PART III - THE FIBRE

Chapter 10 - Cotton, the partner fibre

Denim is a marriage of a dye and a fibre, and the fibre does most of the quiet work. Cotton is a seed hair: each fibre is a single plant cell, spun out by the cotton plant around its seeds, dried into a flat, twisted ribbon of nearly pure cellulose. Under the microscope the twist is visible as convolutions along the fibre's length, and those convolutions are the first secret of cotton cloth - they give the fibres grip on each other, so that short hairs an inch or two long can be spun into a continuous yarn that holds. Denim asks a great deal of its yarn, and cotton, uniquely among the common fibres, could supply what was asked cheaply and at scale.

The plant is a subtropical shrub, grown today across a band of countries from the American South and Brazil to India, China, Pakistan, Uzbekistan and West Africa. It is thirsty and it is attacked by an impressive array of insects, and the argument over what cotton costs the environment is one of the oldest in agriculture. The accusation most often quoted is that cotton occupies only about two and a half per cent of the world's arable land while consuming a grossly disproportionate share of its insecticides - a figure long put at a sixth or more [J48]. The industry body, the International Cotton Advisory Committee, disputes the arithmetic and points to falling pesticide use and rising yields; campaign groups such as Pesticide

Action Network point back to the continued use of highly hazardous pesticides in cotton-growing regions and to poisonings among farm workers [J48] [J49]. What is not in dispute is the direction of travel: genetically modified insect-resistant cotton has cut insecticide spraying in the countries that adopted it, and the remaining problem is concentrated in smallholder systems where the oldest and cheapest chemicals are still the default.

Cotton's water is a similar argument, and it matters to this book because it lands directly on jeans. Cotton is grown both under irrigation and on rainfall, and a global average conceals the difference between a rain-fed field in the American South and an irrigated one in a drying basin. When life-cycle analysts total the water attributable to a pair of jeans, the great majority of it - more than two-thirds in Levi Strauss & Co.'s own assessment - is not the dyehouse or the laundry but the field: the water that grew the cotton [J9]. The fibre, not the factory, is where a jean's water footprint is decided.

For the mill, though, cotton is not a moral question but a specification. Fibre length, strength, fineness and cleanliness are graded and blended; denim, which is forgiving cloth, can absorb shorter and coarser fibre than fine shirting, and the traditional denim mixes leaned on exactly the mid-grade cottons that other goods rejected. That tolerance is one reason denim became cheap work clothing in the first place, and one reason recycled cotton - shorter still after its first life - can return to service in denim more readily than in almost any other fabric. The loop between old jeans and new denim, examined later in this book, begins with the fibre's modest demands.

The plant's botany sorts into two commercial species. Upland cotton, Gossypium hirsutum, supplies the overwhelming majority of world production and essentially all denim: hardy, high-yielding, with medium staple lengths that suit coarse yarns. The extra-long-staple species, Gossypium barbadense - Pima, Egyptian, Sea Island - grows finer and longer fibres for luxury cloth and is irrelevant to denim's bulk. A denim mill buys upland by the bale, graded on staple length, strength, fineness (micronaire) and trash content, and blends across

origins to hold its yarn specification constant through harvests and trade disputes alike.

The production map concentrates in a band of countries that together grow on the order of twenty-five million tonnes of lint a year: India and China at the top, then the United States, Brazil and Pakistan, with West Africa, Uzbekistan, Turkey and Australia filling out the list [J48]. Two structural facts follow. First, most cotton is grown by smallholders - hundreds of millions of people touch the crop - which is why the pesticide and price arguments in cotton are also arguments about rural poverty. Second, the crop is heavily traded: the largest grower, India, consumes most of its own crop at home, while the United States and Brazil export the great majority of theirs. A jean's cotton is among the most international things about it.

Technology has already rewritten the crop once in this century. Insect-resistant Bt cotton, adopted in the mid-1990s and now covering the great majority of acreage in the major producing countries, cut bollworm spraying sharply and lifted yields - one reason the "cotton uses a sixth of the world's insecticides" line, still widely repeated, describes the 1990s better than the present [J48]. The industry's current frontier is less dramatic and more agronomic: better rain-fed varieties, drip irrigation, soil health, and certification schemes - organic, fair-trade, and the mass-market Better Cotton programme through which brands like Levi's committed to source the majority of their cotton [J9]. None of this makes cotton benign; all of it moves the average, and with two billion pairs a year, the average is what counts.

The crop's inputs are the industry's upstream footprint. Cotton occupies a small share of world farmland but consumes an outsized share of its insecticides, a fact documented by PAN UK's long-running surveillance of the crop's pesticide load [J48]; irrigation demands made it the driver of the Aral Sea's destruction [J67]; and its labour history - slavery in the American South, coerced cultivation in colonial indigo and cotton regimes, child labour episodes in modern harvests - makes it the most ethically freighted fibre in commerce [J53]. The jean inherits all of this. When Part VI takes the environmental ledger, it finds that the largest entries were written in the field, before the cloth existed.

The fibre ledger's reformers arrived first, because fibre is where the footprints are largest. Better Cotton - the mainstream standard now covering a substantial share of world production - attacked irrigation and pesticide intensity at farm scale; organic certification removed synthetic chemistry entirely at a price premium; and the recycled programmes attacked the field itself, substituting old garments and factory clips for new bolls [J26] [J47]. PAN UK's documentation of cotton's pesticide load - a small share of world cropland carrying an outsized share of insecticide use - supplies the case the reformers cite [J48]. The trade-offs are real and should be stated: organic yields run lower, recycled fibre shortens and weakens, and every substitution reprices the cloth. The honest ledger counts those too.

The gin determines how much of the field's work the mill ever sees. A modern crop yields roughly a third of its picked weight as lint, the rest going to seed - which has its own economy of oil and meal - and the gin's settings trade lint yield against lint quality: aggressive cleaning raises grade and lowers weight, gentle handling does the reverse. The bale that leaves for the spinner carries its measurements with it - staple length, strength, micronaire (a combined measure of fineness and maturity), colour grade, trash content - and those numbers, not the field's story, are what the spinner buys. Cotton is marketed as a natural fibre and purchased as a specification sheet.

Denim sits comfortably low on that sheet's ladder of demands. The coarse, heavy yarns of a work cloth forgive short staple and moderate strength that a fine shirting could not use, which is one reason jeans could be made wherever cotton and cheap labour met. The modern exception proves the rule: the premium and heritage ends of the market increasingly buy long-staple and extra-long-staple uplands for ring-spun warp yarns, because fibre length shows up in the fabric as strength, smoothness and the quality of the fade. Even in denim, the most forgiving of cloths, the bale decides the ceiling.

Chapter 11 - The gin and the bale

Between the field and the spinner stands one of the most consequential machines in industrial history. Raw picked cotton

arrives with its fibres still locked to the seed; the cotton gin - Eli Whitney's 1793 engine, in the standard telling - drags the fibre through slots too narrow for the seeds to pass. The gin is why cotton is a commodity: it converted a hand-separating chore that capped output into a continuous mechanical step, and in doing so it did more than any other single device to make the American South, and then half the subtropical world, into a fibre farm. Its shadow is long and dark; the explosion of American cotton after 1793 entrenched and expanded the enslaved labour system that picked it. The cloth in the first jeans ever sold in San Francisco was part of that economy, and any honest history of the garment has to carry that fact alongside the inventors and the brands.

Ginned fibre is pressed into bales of several hundred pounds and traded worldwide on grade and staple length. The spinners who buy the bales are the first industrialists in the denim chain, and their craft is to convert a variable agricultural material into a predictable industrial one. Bales are opened, the fibre is beaten and blended to average out the differences between fields and harvests, carded into a soft rope of parallel fibres called a sliver, drawn and re-drawn to straighten it, and finally spun.

It is worth pausing on the blending, because it is the step nobody markets and everybody depends on. Cotton varies by field, by week, by weather; denim must not. A mill's reputation - Kaihara's in Japan, for instance, whose name on a fabric ticket signals consistency to buyers across the world [J16] - rests substantially on the unglamorous discipline of blending and process control that makes this season's cloth indistinguishable from last season's. When the premium market later turned to prize the irregular, slubby character of old denim, mills had to learn the reverse skill: engineering controlled irregularity, which is a much harder trick than it sounds.

The gin's economics deserve the longer view. Whitney's device was simple enough to pirate - he spent the patent in litigation rather than profit - and it spread through the South within a decade. What it mechanised was the bottleneck between plant and market: separating lint from seed by hand had capped a worker's output at a few pounds a day; the gin multiplied it fiftyfold. The consequence was the Cotton Kingdom: within two generations the American South

supplied most of the world's mill cotton, the fibre became the young republic's dominant export, and the enslaved population was expanded and driven to feed the mills of Lancashire and New England. No other machine so tightly binds an industrial history to a moral one, and denim - a cotton cloth made first in New England and North Carolina - is woven directly into that binding.

The modern gin still does Whitney's job, in two mechanical dialects. Saw gins drag lint through ribs too narrow for seed - fast, aggressive, suited to upland cotton; roller gins press seed away between roller and blade - slower, gentler, reserved for the long-staple species. After ginning, hydraulic presses pack the lint into bales of roughly 480 pounds in the American standard, wrapped and sampled for the classing offices where instrument lines grade every bale on length, strength, colour, trash and fineness. The bale, not the field, is the unit in which the world's spinners think.

Contamination is the trade's running sore and its quality frontier. A fragment of polypropylene sack or a plastic film shred, carded into yarn, makes a coloured fault in cloth that no dye will hide; sticky honeydew from aphids gums the spinning frames. Mills pay premiums for clean bales and police their lay-downs, because in a product whose entire promise is uniform colour and long wear, a contaminated yarn is not a defect but a recall. The care taken here is invisible to the wearer - which is the definition of quality working properly.

Whitney's 1793 machine is usually told as invention; its real legacy is throughput. The saw gin tore lint from seed with wire teeth on a rotating cylinder, and it made short-staple upland cotton - the stubborn, green-seeded variety that grew across the American interior - economically separable for the first time. The roller gin, the older Indian churka principle mechanised, survived for the long-staple varieties the saws would damage. The two machines still divide the world's crop between them: saws for the upland bulk, rollers for the fine long staples, each bale traceable to a gin and often to a module in a particular field.

Contamination is the trade's running sore and its quality frontier. A single polypropylene strand from a bale wrap, a scrap of plastic

mulch film, a tuft of human hair - any of these, shredded through opening and carding, becomes thousands of coloured specks in white weft or foreign fibre that dyes differently in indigo. Mills buy detection machinery and ginners sell cleanliness as hard as they sell staple; whole premium programmes exist to hand-pick or machine-vision the trash out before the card. The bale is the last point where the fibre is cheap to fix; every stage after it multiplies the cost of what was missed.

Chapter 12 - The yarn

Spinning inserts twist into drafted fibres and thereby makes yarn, and denim's two spinning technologies draw a line through its quality tiers. Ring spinning, the older method, drafts the sliver through rollers and winds it onto a bobbin driven by a travelling ring; the twist runs the full length of the yarn and the fibres lie tight and parallel. Ring-spun yarn is strong, fine and slightly irregular in a way the eye reads as character. Rotor spinning - open-end - feeds fibre into a spinning rotor that collects and twists it in one continuous operation, three or four times faster than ring frames and without the winding steps. Rotor yarn is cheaper and bulkier, but the fibres inside lie less ordered, the yarn is weaker and hairier, and cloth woven from it fades flatter and wears less gracefully.

The mass market runs largely on rotor-spun weft and a mixture of the two for warp; the heritage and premium markets specify ring-spun warp and weft, and say so on the label. The difference is not snobbery alone. Denim's ageing depends on how the yarn releases its dye shell and how the fabric surface moves under abrasion, and both behaviours differ measurably between the yarn types. A vintage Levi's 501 from the middle of the twentieth century - the object the whole reproduction market exists to imitate - was woven from ring-spun yarn, and part of what the imitators are buying when they pay for ring spinning is the right to fade like the old cloth.

Then there is slub: deliberate thick-and-thin variation along the yarn. Old spinning frames drifted, and old denim consequently had texture; when modern machinery made yarn perfectly even, cloth

became flat and the market discovered it missed the flaw. Slub is now programmed - the draft rollers are electronically disturbed to spin irregularity to a specified frequency and amplitude, and a mill can offer "vintage character" the way a synthesiser offers piano. The detail is small and the lesson is large: in a mature commodity industry, the imperfections of obsolete technology become design parameters of the new.

Yarn count frames the choice of machine. Denim warps and wefts run coarse - in cotton count, roughly Ne 6 to 20, against forty and upward for shirtings - and coarse counts forgive: rotor spinning's weaker, bulkier yarn is perfectly serviceable in a heavy cloth, which is why the mass market spun so much of its denim open-end from the 1970s onward. Ring spinning held the warp of the quality tiers, where strength at the loom and character in the fade pay for the slower frames. The two technologies still partition the market: rotor for volume and price, ring for hand and heritage, with the label increasingly willing to say which.

The stretch revolution entered through the yarn, and its engineering is elegant. A core-spun yarn draws a filament of elastane - polyurethanes invented by Joseph Shivers at DuPont in the 1950s and marketed as Lycra, the fibre that can stretch to five times its length and recover [J46] - through the centre of the drafting zone while cotton fibres are twisted around it: an elastic spine in a cotton sleeve. Woven as weft, it gives jeans their modern give and recovery. The cost, as Part VIII will count, lands at the garment's end of life: the elastic spine is a contaminant in the cotton recycling stream, one of the circularity programme's named obstacles [J22].

Slub, nep, and the other planned imperfections complete the yarn designer's palette. Where a vintage loomstate cloth gained its texture from frame drift and uneven carding, the modern slub yarn is programmed - drafting rolls oscillated by servo to thicken and thin the yarn at set intervals and amplitudes, in patterns a mill can dial like a font. The result lets a modern mill sell "character" as a reproducible specification: the irregularity that the heritage market prizes, delivered with the consistency that modern retail demands. It is a small, perfect emblem of the whole denim business - nostalgia, manufactured to tolerance.

Stretch's technical architecture deserves one more paragraph, because it changed the factory as well as the fit. An elastane-core yarn - a filament wrapped in cotton - behaves unlike spun cotton under tension and heat: it grows in washing, contracts in drying, and skews if mishandled, so mills added heat-setting to the finishing line and factories recalibrated cutting and sewing allowances. The garment that results is dimensionally managed rather than dimensionally stable, and the consumer's complaint about jeans that bag at the knees is the fibre's physics surfacing through the marketing. The industry learned to dose the stretch - one percent for shape, two or more for leggings-adjacent fits - and the dose became a spec-sheet number alongside weight and dip count [J46].

The two spinning systems make two different denims, and the market sorts them without most buyers ever knowing. Ring spinning - the nineteenth-century frame, refined - drafts and twists the fibre into a yarn with a soft, irregular, slightly hairy body; it is slow and costly, and it makes the strong, characterful warps of premium denim, the cloth that breaks in and fades with contrast. Open-end or rotor spinning drops the fibre into a spinning rotor and lets centrifugal force build the yarn: several times faster, cheaper, more even - and harder, leaner, less lively. The mass market runs largely on rotor-spun weft and a mixture of the two in warps; the heritage market specifies ring-spun warp and weft and pays for it. When a reviewer writes that a fabric has character, half of what is meant happened at the spinning frame.

Core-spun stretch yarn deserves its engineering note. The elastane filament at the centre is fed into the drafting zone under controlled tension - draft too little and the yarn snaps back unevenly; draft too much and the filament breaks and the seam will grin. The cotton sheath must fully cover the core or the garment will show shiny streaks where the elastane peeks through. The spinner controls the draw ratio, the weaver adds heat-setting downstream, and the laundry finishes the job of stabilising a fabric that is, by design, never entirely stable. A pair of stretch jeans is a managed truce between a fibre that wants to recover and a garment that wants to keep its shape [J46].

Chapter 13 - The loom and the finish

Dyed warp and undyed weft meet at the loom, and the modern denim loom is a very different machine from the one that wove the first Levi's cloth. The shuttle looms described in Part I gave way, from the 1950s onward, to Sulzer projectile looms - which grip single weft picks and fire them across - and then to rapier and air-jet machines. Speed multiplied several times over; widths doubled; labour per metre collapsed. Denim became one of the true commodity fabrics of world trade, woven by the hundreds of millions of metres in China, Pakistan, India, Turkey, Mexico and Brazil [J8].

What comes off the loom is not yet the cloth in a shop. Loomstate denim is hard, hairy, faintly smelly of size - the starch or synthetic coating applied to warp yarns to survive weaving - and, crucially, unstable. Cotton yarns spun under tension relax when wetted, and the fabric shrinks; unsanforized denim can lose a tenth of its length in the first wash, which is a charming quirk for hobbyists and a warranty disaster for a mass brand. The answer, invented in the late 1920s by Sanford Lockwood Cluett of the Cluett Peabody company, is compressive shrinkage: the cloth is wetted and then mechanically squeezed against a heated, shrinking rubber blanket, pre-shrinking it in the factory so the garment will not shrink at home. The process was patented, trademarked as Sanforized, and licensed worldwide; by the mid-1930s Blue Bell was advertising Super Big Ben overalls in "100% Sanforized fabric that reduces shrinkage to less than 1%" [J47] [J11]. The small printed word on the pocket flashers of mid-century jeans is one of the great quiet quality innovations of the clothing industry: fit that survives the first wash.

Finishing does the rest of the tailoring of the cloth's character. Singeing burns the fuzz from the face; skewing deliberately twists the fabric against its natural torque so that legs hang straight after washing; mercerising under caustic tension adds lustre and strength; calendering irons the surface. Then come the choices that define a product family: desizing and a rinse for one-wash cloth, resin for a pressed crease, or nothing at all for raw denim sold loom-stiff to enthusiasts who prefer to do the breaking-in themselves. By the time

a roll of denim is wrapped for a garment factory, the fibre, the dye, the weave and the finish have each contributed a layer of behaviour. The garment maker receives all four decisions already locked into the cloth - and, as Part VI will show, then adds a fifth layer entirely of its own: the wash.

The looms that replaced the shuttle each made a different bargain. Projectile machines, pioneered by Sulzer, grip a single weft and carry it across in a small metal gripper - fast, wide, and robust in heavy yarns, which made them the denim standard of the late twentieth century. Rapiers trade a little speed for flexibility of yarn and pattern; air-jets blow the pick across and win on raw pace in light to medium cloth. All three cut every pick at the selvedge, and all three more than doubled the width and multiplied the speed of the old shuttle frames. The world's denim now comes overwhelmingly off such machines, in cloth a hundred and fifty centimetres and wider, at prices the shuttle mills could never meet [J8].

Finishing then corrects what weaving leaves. The standard sequence runs: singeing, to burn the fuzz from the face for a cleaner, sharper twill; desizing and scouring, to strip the warp's protective size; skewing, which deliberately torques the cloth against its natural twist so that legs hang straight through the wash cycle of a consumer's life; then the compressive-shrinkage range - the Sanforizing line - where the wetted cloth is squeezed lengthwise against a thick rubber belt as it dries, pre-shrinking it to a guaranteed tolerance [J47]. The process, patented by Sanford Cluett's Cluett Peabody firm and licensed worldwide from the 1930s, turned "will not shrink out of fit" from a hope into a specification printed on pocket flashers; Blue Bell advertised one per cent shrinkage as a selling point by 1936 [J11].

The last choices are commercial. Loomstate or raw cloth ships as-is to brands and hobbyists who want the full stiff, shrink-prone original; one-wash cloth is rinsed at the mill for softness with the colour intact; resin finishes bake in permanent creases or add water and stain resistance. The same physical roll can thus be the start of a thirty-dollar supermarket jean or a three-hundred-dollar repro, and which one is decided not at the loom but in the finishing schedule - the last of the mill's four locked-in decisions.

Sanforization's story is the era's emblem. Shrinkage had been the jean's accepted hazard - buy big, wash down to fit - until the Sanford Cluett patents of the late 1920s and the process's commercial arrival in the early 1930s made controlled pre-shrinking a machine operation [J46b]. Levi's adopted it and advertised it; the guarantee that the size on the ticket was the size after washing removed the last major uncertainty from a mail-order garment, and it mattered precisely because so much of the garment's market was remote from any fitting room. The mechanical elimination of surprise is a recurring theme in this book: the industry's advances are, again and again, ways of making the product more predictable - sanforized cloth, standardised fits, computer-controlled washes - while its mythology sells the unpredictable, the unique fade, the personal garment.

Each shuttleless family made its bargain with the cloth. Projectile looms grip the weft and carry it across in a small steel carrier - versatile, gentle on coarse yarns, the workhorse of much quality denim. Rapier looms pass the pick between flexible tapes or rigid rods - the most versatile of all, and common in the mills that change styles often. Air-jet looms blow the pick across on compressed air - fastest and cheapest per metre, dominant in volume denim, and limited to yarns that can take the blast. The choice among them is a mill's second identity after its dye range: a mill running vintage Draper shuttles and one running air-jets can buy the same yarn and sell into different worlds.

Finishing chemistry completes what the loom leaves raw. Beyond singeing and sanforizing - the compressive shrinkage process patented by Sanford Cluett and standard by the 1930s [J46b] - the range may skew the fabric deliberately to pre-counter the twill's torque, calender it between rollers for flatness or lustre, pad on softeners, or apply resin for permanent press. Each treatment is invisible in the shop and decisive in the wash. The consumer's question "will these shrink or twist?" is answered entirely here, weeks before the garment is sewn, in a hall the customer will never imagine.

PART IV - THE PATENT

Chapter 14 - Reno, 1871

The story of the blue jean's invention is unusually well documented for a nineteenth-century product, because it runs through a patent, and patents leave paper. The paper begins in Reno, Nevada, with a tailor named Jacob W. Davis, a Latvian-born immigrant who had worked his way across North America - Canada, the Panhandle, Virginia City - and settled in Reno in the late 1860s making tents, wagon covers and horse blankets for the railroad and mining trade [J1] [J50].

Davis bought his fabric on credit from a San Francisco dry-goods wholesaler: Levi Strauss & Co., which supplied his duck cloth and denim. The origin story the company has told for a century and a half is essentially the one in the historical record. A customer - in the standard version, a labourer's wife, who needed trousers that would not fall apart on her husband - commissioned work pants, and Davis, who had been riveting the stress points of his horse blankets, put copper rivets at the pocket corners and the base of the fly. The pants held. Word moved, orders multiplied, and Davis found himself making riveted "waist overalls" in ones and twos while suspecting, correctly, that he was sitting on something bigger than his bench.

What Davis did not have was sixty-eight dollars - the fee to file a patent - or the machinery to exploit one. What he had was a supplier

with money, a head for business, and every incentive to own a bestseller. In 1872 Davis wrote to Levi Strauss proposing that they take the patent out together: Davis the inventor, Strauss the capitalist [J50]. It is one of the cleanest small-business bargains in the industrial record - the maker with the idea and the merchant with the means - and it deserves to be told without myth on either side. Davis was not an employee whose idea was absorbed; he was the patent's named inventor, he moved to San Francisco to run the manufacturing, and he supervised Levi Strauss & Co.'s riveted-garment production for the rest of his working life. The company got the invention. The tailor got a career.

There is also a lesson in what the invention was. Davis did not invent work trousers, or denim, or rivets, or copper. He identified a precise mechanical failure - seams at pocket mouths ripping under the daily strain of hands, tools and ore samples [J1] - and applied a fastening already proven in his other trade. The history of industrial innovation is full of such transfers, a solution wandering from one craft to another in the pocket of a working man. The jean was not dreamed up as a product category; it was a fix that escaped its niche.

Davis deserves the fuller portrait the record allows, because the invention makes more sense in his hands than in a boardroom's. He was a working tradesman of the railroad West: he had cut and sewn the heavy duck and canvas goods - tents, wagon covers, horse blankets - that the mining and rail towns consumed, and he bought his cloth, on account, from Levi Strauss & Co. in San Francisco [J50]. The rivet was a tool of that trade, the standard way to keep a blanket's straps and a cover's corners from tearing out. The customer story - a labourer's wife commissioning trousers that would survive her husband - puts the transfer in one scene: a tailor reached for the fastening he already trusted and put it where pockets actually fail [J1].

The detail that gives the story its texture is the pockets' contents. The men who tore their trousers were miners and rail workers who carried ore samples, tools, tobacco and nails in them; the pocket mouth, where a hand enters a hundred times a day and a loaded pocket swings, is precisely where a seam's thread is worked against its weave. Davis's patent specification says it plainly - seams "ripped

or started by the placing of the hands in the pockets and the consequent pressure or strain" [J1]. This was not fashion. It was a fatigue failure in a component under cyclic load, fixed by moving the load from thread to metal.

After the patent, the partnership ran the way the letter proposed. Davis moved to San Francisco and supervised Levi Strauss & Co.'s manufacturing - the cutting rooms and sewing lines where the riveted waist overalls were made - and he stayed with the firm for the rest of his working life, decades of quiet production management after his one loud idea [J50]. The company kept his name on the patent and, much later, put it on a heritage brand. The inventor's arc - one good fix, then a career inside the business it built - is a more common industrial pattern than the lone-genius story, and a more instructive one.

The patent's expiry in 1890 is the hinge on which the whole competitive history turns. For seventeen years Levi Strauss & Co. held the only legal right to sell riveted work clothing in America; afterwards the market filled with rivals, and the company's defences had to move from law to brand - the Two Horse mark, the arcuate stitching, later the red tab and eventually litigation to defend them all [J1] [J2]. The sequence prefigures the industry's permanent condition: no one owns the jean; everyone owns some mark upon it. Trademark, not patent, is the jean's natural legal instrument, because the product is an old idea and the identity is the asset.

The lot-number system belongs to the same story of identity constructed without patent protection. 501 for the waist overall, 201 for the budget line, numbers for jackets and engineers' coats - the numbers let a fragmented distribution network of country stores order reliably from a catalogue, and they accidentally created the collecting taxonomy of a century later, in which a "big E" 501 of a particular decade is an identifiable, priceable historical object [J69]. Industrial record-keeping became connoisseurship's map.

Reno in 1871 was a railway and mining supply town at the foot of the Sierra, full of men whose work ate trousers: freight teamsters, mill hands in the Comstock's timber and ore trades, railroad crews on the Central Pacific. Davis had been making horse blankets and

wagon covers - the heavy sewn goods of a frontier economy - and his customers brought him their trousers to strengthen. The pocket was the failure point because the pocket was the toolbox: it carried a miner's or teamster's daily weight of nails, tobacco, knife and coin, and the load concentrated exactly where the pocket's corner stitches met the body cloth [J50].

The letter Davis wrote to Levi Strauss survives in substance, and it is a model business document: he named the improvement, said what it was worth, admitted he could not fund the patent, and proposed the partnership - Strauss to supply capital and the cloth, Davis to supply the invention and, later, the factory management. The division held for the rest of Davis's working life. The tailor from Riga ended his days a prosperous San Francisco manufacturer; the rivet outlived them both. It is hard to find a cleaner case in industrial history of the inventor-merchant split, or one where the handshake was honoured so long [J50].

Chapter 15 - Patent 139,121

On May 20, 1873, the United States Patent Office granted Jacob W. Davis and Levi Strauss patent number 139,121 for an "Improvement in Fastening Pocket-Openings." The specification is a single elegant page. The problem: "the seams are usually ripped or started by the placing of the hands in the pockets and the consequent pressure or strain upon them." The solution: "a metal rivet or eyelet at each edge of the pocket-opening," headed down on both sides through the seam, so that the strain is borne by the metal and not the thread [J1].

A patent is a fence, and this one fenced off the only practical way to make work pants survive industrial labour. For the seventeen years of its term - 1873 to 1890 - Levi Strauss & Co. alone could sell riveted clothing in the United States, and it defended the monopoly with energy. The National Archives' account of the episode is titled "Forever in Blue Jeans - and in Court": the company sued imitators repeatedly through the 1870s and 1880s, and the litigation record is one of the reasons historians can reconstruct the trade so precisely [J50]. The monopoly was not merely lucrative; it was formative.

Seventeen protected years let one firm define the product category so completely that when the patent expired, the market did not fragment into generic riveted pants - it organised around the standard Levi Strauss had set, with rivals differentiating around the edges of an established form.

The expiry in 1890 is the hinge of the industry's early history. Competitors who had waited out the term entered immediately, and the company's answer was characteristic: it leaned on the brand it had built under protection. In that same year it assigned the lot number 501 to its copper-riveted waist overalls - the beginning of the most durable product number in clothing - and the garment that had been sold as a patent became a garment sold as a name [J2]. The Two Horse trademark, showing two teams failing to pull a pair of the pants apart, had already been introduced in 1886, in part as a mark legible to customers who could not read English at all [J2].

It is hard to overstate how much of the modern jean was settled in these two decades. The five-pocket form, the rivets, the orange linen thread, the arcuate stitching on the back pockets, the waistband, the watch pocket - all present or arriving by the time the patent ran out. Every subsequent history of the product, including the designer, premium and fast-fashion eras, is a variation on a design frozen by litigation and habit before 1890. Few mass objects are so old so early.

The litigation record is a history in itself. Through the 1870s and 1880s Levi Strauss & Co. sued the imitators who attached rivets to their own work pants, and won often enough to hold the monopoly; the National Archives' telling runs through case after case, because federal court records are where the paper survives [J50]. The doctrine the cases settled mattered beyond clothing: a use patent on a fastening, applied to a garment, could fence off an entire product category, and for seventeen years one company owned the only credible answer to the working man's main wardrobe complaint.

Monopoly rents did what they always do - they built the moat that outlasted the grant. Protected from direct competition on the critical feature, the company invested in everything around it: the Two Horse trademark legible to non-readers of English [J2], the graded

cloth from Amoskeag, the distribution through every dry-goods channel in the West, and the simple reputational fact that "Levi's" meant the riveted pants. When the patent expired in 1890 and the field opened, rivals could copy the rivet but not the seventeen years; the lot number 501 assigned that same year turned a product feature into a named, numbered standard [J2].

The precedent set then still runs the industry. Levi Strauss & Co. became, and remains, one of the most litigious trademark holders in apparel, defending its tab, its arcuate stitching and its pocket patterns against imitators in courts on several continents - the same strategy as the 1870s, updated for a world where the enforceable asset is not a fastening but a set of visual marks. The jean's first seventeen years under patent taught its owner the lesson it never forgot: in a product anyone can sew, the law is part of the design [J50].

The claims themselves deserve quotation in substance, because their modesty is the point. Davis and Strauss did not claim trousers, or rivets, or work clothing; they claimed "an improvement in pantaloons" - the fastening of pocket openings with metal rivets or studs at the points of strain. The drawings show a garment entirely conventional for 1873: no one looking at the patent sees the future in it. What the patent actually fenced was a method of repair-proofing, and its breadth was that it covered any garment so reinforced. That narrow, practical claim - almost a tailor's trick, written as law - turned out to be the founding document of an industry [J1].

May 20, 1873 - the grant date - is now observed by Levi Strauss & Co. as the birthday of the blue jean, celebrated with the seriousness other industries give to anniversaries of engines and light bulbs [J69]. The birthday is marketing, but the date is real, and the document behind it has a fair claim to being the most consequential single patent in the history of clothing: not for what it invented, but for what it standardised. After 1873 the American work trouser had a specification, and the specification had owners.

Chapter 16 - Waist overalls

What exactly did the protected product consist of? The pants were sold as "waist overalls" - overalls worn at the waist, distinct from the bib overalls that covered the chest - and the cloth came east by rail. Levi Strauss & Co. did not weave; it bought. Its denim in the early years came from the Amoskeag Manufacturing Company of Manchester, New Hampshire, then the largest textile mill complex in America, whose heavy "XX" denim - the double-extra grade stamped on the waistband - gave the pants their substance. The company's own archives record the switch that fixed the garment's modern character: by 1915 it was buying its denim from Cone Mills of Greensboro, North Carolina, beginning a supplier relationship that would run for more than a century and make the names Cone and Levi's almost interchangeable in the denim trade [J8].

The product evolved by small, dated increments, and the increments are worth listing because they show a garment being tuned to working lives. Belt loops appeared in 1922, in response to the belt displacing suspenders; the cinch-back at the rear waist survived alongside for decades before being dropped. The back-pocket rivets, which scratched saddles and school chairs, were pushed to the inside of the pocket in 1937 - concealed rivets - after complaints that the metal damaged furniture. In 1936, to distinguish the pants from the rivals swarming after patent expiry, the company folded a red tab into the right back pocket seam, a device so small and so effective that it has been in place ever since [J2]. The first women's jeans followed the dude-ranch vogue of 1934 under the name Lady Levi's [J2]. The zipper did not arrive on the 501 until 1954, and then only on a variant for the Eastern market, where buttons were thought strange.

Beneath the increments, the economics of the garment were also settling. Waist overalls were priced for the working man and sold through the same dry-goods channel that sold his boots and shirts; the jean was hardware as much as apparel. The customer bought durability, the company sold it, and the Two Horse mark promised it in pictures. This contract - you pay for the toughest trousers that can be made - is the foundation on which the entire later structure of meanings was built. When jeans became fashion, they sold the memory of that contract; when they became global, they exported it;

and when critics today ask whether a garment built to be durable should really be manufactured at two billion pairs a year, they are pointing at a contract the industry itself wrote.

The early garment differed from today's in telling details, and the differences date its evolution. The first waist overalls had a single back pocket; the second arrived as the form settled. They carried suspender buttons on the waistband and a cinch strap with a buckle at the back - the standard waist adjustment of the suspender era - and a rivet at the base of the fly as well as at the pockets. The cloth was Amoskeag's heavy XX denim out of Manchester, New Hampshire, the product of the largest textile complex in the country, bought by the bale and cut in San Francisco [J8]. "XX" on the label was the grade, and the grade was the promise.

The dated increments then track the changing body and its habits. Belt loops appeared in 1922 as belts displaced suspenders, though the cinch-back lingered into the 1940s [J69]. The red tab was folded into the back-pocket seam in 1936, a defence against the post-patent crowd [J2]. The exposed back-pocket rivets, which gouged saddles and school desks, were driven inside the pockets in 1937 after the complaints piled up - the "concealed rivet" era - and the crotch rivet had already gone by then. The zip-fly option of 1954, the 501Z, marked the garment's concession to the zip's national victory [J69]. Each change was small, dated, and permanent; read in sequence they show a product converging on its final form the way a river settles into its channel.

The cloth, meanwhile, made its defining move south. By 1915 Levi Strauss & Co. was buying from Cone Mills of Greensboro, and the relationship - Levi's specifying, Cone weaving - became the longest-running supplier partnership in American apparel, the arrangement under which White Oak's looms made the cloth of the classic 501 for most of the twentieth century [J8]. When the patent, the number, the tab, the loops and the cloth had all arrived, the modern jean existed; everything since has been styling, marketing and world expansion on top of a finished design.

The catalogue era's scale is easy to underrate. Montgomery Ward and Sears Roebuck carried work clothing to every farm gate in America,

and denim overalls and jackets were staple lines, sold on the same pages as harness and seed. The catalogue fixed national prices for a garment previously subject to local markups, and it taught the industry a lesson it would relearn with each new channel - the department store, the mall, the internet: the jean follows distribution, and each new route redraws the brands' pecking order. The direct-to-consumer shift of the 2010s, Levi's rebuilding itself around its own stores and website on the way back to the stock market in 2019, is the catalogue lesson in digital dress [J62].

Advertising professionalised alongside. The two-horse patch had made a guarantee visible; twentieth-century advertising made the mythology audible - cowboy imagery, then youth imagery, then the global campaigns that sold the 501 as an idea with a button fly. The spending built the first garment brand that a person anywhere on earth could name, and it established the economics of Part VII: in jeans, demand is manufactured as deliberately as cloth.

The firm's early decades read as steady industrialisation of a good idea. Strauss's wholesale house supplied the West's dry-goods merchants; the riveted "waist overalls" - the period's name, jeans not yet standard - sold through catalogues and counter displays; lot numbers distinguished the products, with 501 assigned to the flagship waist overall by 1890. The San Francisco earthquake and fire of 1906 destroyed the company's headquarters and its records, which is why the early archive is thin and why so much of the garment's pre-1906 history is reconstructed from patents, advertisements and surviving garments rather than company minutes [J2]. The product outlasted its own paperwork - an early instance of a pattern this book meets repeatedly: the jean as a thing more durable than the institutions around it.

The frontier economy into which the waist overall was born deserves a sketch, because the garment was priced and built for it. Mining camps and railroad gangs bought clothing with wages that ran to a few dollars a day; a work garment had to last months of abrasion and be cheap enough to replace without grief. Strauss's genius was distribution as much as manufacture: his wholesale house already reached the West's dry-goods stores, and the riveted overall dropped into an existing channel that competitors had to build from scratch

[J2]. The catalogue page and the general-store counter were the garment's first media.

The waist overall sat at a deliberate price point. It was not the cheapest trouser in the catalogue - cheap work pants were made of lighter drilling and unbranded cloth - nor anything like a luxury: it sold at a small premium justified by the guarantee, positioned where a workingman would pay once for durability rather than twice for replacement. The two-tier strategy came early: the 501 carried the best 9-ounce Amoskeag denim and the full five-pocket pattern, while the 201 and other lower lots trimmed cloth and finish to meet a lower price. The industry's permanent structure - one garment, several price grades, the difference invisible until the wash - was present from the first catalogue page [J2].

The Amoskeag arrangement matters beyond procurement. The Manchester, New Hampshire mill was then among the largest textile factories on earth, and its XX denim - the trade term for the best grade - gave the young company's product a cloth pedigree to match its hardware patent. When Levi Strauss switched its flagship supply to Cone Mills in 1915, the pattern repeated: the garment maker's brand rode on a named mill's cloth. A century later, when Cone's White Oak plant closed, the grief in the trade press was precisely for this - the last link in a supply relationship that had become part of the product's identity [J14].

Chapter 17 - Three houses

American jeanswear consolidated around three companies, and their founding stories make a tidy comparative study in how industries grow.

Levi Strauss & Co. was the merchant's house: a dry-goods importer that owned an invention, bought its cloth from others, and built the category under patent protection. Henry David Lee's was the distributor's house. The H.D. Lee Mercantile Company of Salina, Kansas, founded in 1889, dealt groceries and goods to the West before it manufactured anything; it moved into making workwear in 1912 and made its name with a problem-solving garment - the

Union-All of 1913, a one-piece coverall born when a driver asked the Salina factory to sew a jacket to a pair of pants, so that men who had to crawl under unreliable automobiles would not dirty their clothes. Lee registered the name in 1914 and claimed within two years that there was "a suit of Union-Alls under the seat of every auto" [J10]. Lee's later cowboy line, the Riders, and the slim "Westweave" Westerners of the 1950s, carried the house into western wear [J10].

The third house was the factory's. C.C. Hudson was a Tennessee farm boy who left Spring Hill Farm in 1897 to sew buttons for twenty-five cents a day in a Greensboro, North Carolina overall factory; when the factory closed in 1904, he and his brother Homer bought several of its sewing machines and opened the Hudson Overall Company in a loft over a grocery on South Elm Street [J11]. The Hudsons' company became the Blue Bell Overall Company in 1919, was bought by Big Ben Manufacturing in 1926 - keeping the Blue Bell name and the Greensboro address - and in 1947 launched the product that made it: Wrangler authentic western jeans, model 13MWZ, cut for saddle wear by a celebrity tailor known as Rodeo Ben and wear-tested and endorsed by professional rodeo cowboys Jim Shoulders, Bill Linderman and Freckles Brown [J11]. Wrangler's authenticity ran through the arena rather than the mine, and it still trades on being the official jean of professional rodeo [J11].

Merchant, distributor, factory: three routes to the same shelf, and three different corporate destinies. Levi Strauss remained a family-controlled business, public only in two separated spells. Lee was bought by Vanity Fair Mills in 1969, the nucleus of the giant VF Corporation, which swallowed Blue Bell in 1986, uniting the second and third houses under one roof [J8]. And when VF eventually decided to concentrate elsewhere, it spun Wrangler and Lee off together in 2019 as Kontoor Brands - the two oldest rivals in jeans as stablemates [J12]. The wheel of consolidation and separation in this industry never really stops turning.

The rivals' product lines repay a closer look, because each house answered the same question - what should a working man wear? - with a different emphasis. Lee's answer was coverage: the 1913 Union-All, born from a driver's request to sew jacket to pants, sold

the idea that the whole body could be protected by one garment, and the company's own advertising claimed a suit under the seat of every car within two years [J10]. Lee carried the same problem-solving posture into western wear - the Riders line for cowboys, the slim Westweave Westerners of the late 1950s with rodeo champion Casey Tibbs as spokesman, and Lady Lee Riders from 1947 for the women the industry had half-ignored [J10].

Blue Bell's answer was identity. C.C. Hudson's little Greensboro loft company, founded on bought-back sewing machines in 1904, grew on plain work overalls, became Blue Bell in 1919, survived sale to Big Ben in 1926, and advertised modernity through its fabric - Super Big Ben overalls in one-hundred-per-cent Sanforized cloth in 1936, shrinkage under one per cent as a printed promise [J11]. The masterstroke was an acquisition: in 1943 Blue Bell bought the Casey Jones Company, a work-clothes maker, and with it the rights to a rarely used brand name - Wrangler [J11]. Four years later the 13MWZ, designed by Rodeo Ben and endorsed by rodeo's reigning champions, put the name on the map it still occupies [J11].

The structural difference between the houses foretold their corporate fates. Levi Strauss owned a brand and a patent and bought its cloth; Lee owned distribution and then factories; Blue Bell was a factory that bought a brand. When consolidation came, the factory house and the distribution house ended up under the same corporate roof - VF Corporation - while the brand house stayed independent. The modern map still shows the seams: Levi Strauss & Co. listed on the New York Stock Exchange, Wrangler and Lee together in Kontoor Brands, and the factory logic of 1904 readable in both [J12].

The houses' advertising told the same story in three dialects. Levi's sold the guarantee - the two horses pulling uselessly at a pair of pants - and later the West and youth itself; Lee sold practicality and innovation, the Union-All and the zip; Wrangler sold professional endorsement, the rodeo cowboy whose living depended on the garment. None of the three ever sold fashion in these decades, because the customer was not buying fashion. The remarkable thing about the mid-century jean business, looking back, is how little of its revenue came from persuasion and how much from habit: men wore out work clothes and bought the brand their work gang wore. The

marketing departments' job was to not lose that customer - a job description that explains why all three houses were caught so unprepared when the garment's meaning changed under them.

The geographic division of loyalty was real enough to map. Levi's owned the Pacific slope and the mining West it had been born in; Lee ran strong through the Plains and the farm belt its Kansas warehouses served; Wrangler, founded in North Carolina and cut for the saddle, took the South and the rodeo circuit. A man's brand said where he was from, and the brands' national expansion in the postwar decades was as much a conquest of each other's territories as of new demand. By the 1960s all three were national, all three were advertising on television, and the regional map had blurred into a simple hierarchy of price and image.

Chapter 18 - Greensboro

Every industry has a town, and denim's was Greensboro, North Carolina. The logic was the standard logic of the mill South: cotton was grown nearby, coal came by rail from the Virginia fields, the railroad carried finished cloth away, and labour was cheaper than in New England. When the Baltimore merchants Moses and Ceasar Cone found their supply of fabric irregular in the 1890s, they did what vertical integrators always do - they built their own mill. Proximity Manufacturing began in Greensboro in 1895; the White Oak mill followed in 1905 and grew into the largest denim producer in the country; the Cone company claimed that by 1910 a third of the world's denim came from its Greensboro plants [J8]. Blue Bell sewed its overalls in the same town, and later VF Corporation kept its headquarters there [J8].

White Oak is the mill that denim people speak of the way wine people speak of a vineyard. Its product - heavy, ring-spun, rope-dyed selvedge denim woven on old narrow Draper shuttle looms - was the reference cloth of the American industry, and from 1915 onward it supplied Levi Strauss & Co. under a relationship so long-running it amounted to co-development [J8]. The 501's cloth, through its classic decades, was White Oak cloth. The plant's size, though, was

calibrated to a world that was leaving: as jeans manufacture moved to Mexico and then Asia through the 1980s and 1990s, the fabric orders followed the sewing, and a mill built for volume found itself with more capacity than its shrinking customer list could fill [J14].

The end, when it came, was announced in the language of a business decision. In October 2017, International Textile Group, Cone Denim's parent, said the White Oak plant would cease operations on December 31, 2017, after 112 years of continuous production, because customers had shifted fabric sourcing outside the United States and the plant's scale made its costs unsupportable [J14]. The trade press recorded what the announcement understated: this was the last American mill weaving selvedge denim on the old looms [J15]. Levi's itself published a farewell. Enthusiasts stockpiled the cloth. Some of the Draper looms were saved and moved - a few to a small North Carolina operation weaving White Oak patterns again on a craft scale - but the industrial era of American denim ended that December, not with a failure but with an arithmetic: nobody needed that much of that cloth, made there, any more.

Greensboro's arc - cotton, coal, rail, one-third of world output, then a closed gate - is the arc of textile manufacturing in the high-income world, compressed into one town. The making of denim did not decline; it moved. Part VI follows it.

The Cone brothers' entry was a textbook vertical integration, and its scale still startles. Moses and Ceasar Cone ran a Baltimore grocery and jobbing business that sold mill goods across the South; tired of irregular supply from the North Carolina mills they bought from, they built their own. Proximity Manufacturing, begun in 1895, took its name from its logic - proximity to cotton, coal and rail. White Oak, named for a giant tree on the site, followed in 1905 and grew into the largest denim plant in the United States; the company's claim that one-third of the world's denim came from its Greensboro mills by 1910 captures the town's peak [J8].

The cluster around the Cones made Greensboro denim's company town. Blue Bell sewed overalls a short ride from the mills that wove its cloth; Burlington and Erwin and the other Piedmont names filled out the region's weave sheds; and after Vanity Fair Mills bought

H.D. Lee in 1969 and renamed itself VF Corporation, the headquarters of what became the world's largest apparel group sat in the same town [J8]. When Levi Strauss chose Cone for its denim in 1915, it bound the industry's biggest brand to the industry's biggest mill for a century, and the 501's cloth became White Oak's signature product.

The unravelling, when it came, came through the same arithmetic that built the town. As jeans sewing moved to Mexico and Asia, the fabric orders followed the needle; a plant scaled for national volume found its order books thinning and its costs fixed [J14]. ITG's 2017 announcement - closure effective December 31, order volumes "significantly reduced", capacity unsupportable - ended 112 years of continuous production [J14]. The obituaries noted what the press release could not: the last American selvedge looms stopped, the Levi's farewell was published, and the cloth of the 501 passed fully to foreign mills [J15]. Greensboro still has the headquarters buildings. The looms are gone, and with them the industry's first geography.

White Oak's opening in 1905 completes the vertical-integration story the mill's closing ended. Cone Mills, founded by the Cone brothers in Greensboro, North Carolina, had supplied Levi's with cloth since the 1910s under a handshake arrangement that became one of American industry's longest supplier relationships; the White Oak plant wove the 501's denim for most of the twentieth century, on looms that included, to the end, the old Draper X3 shuttles the reproduction market coveted [J14]. The "Golden Handshake" - as the Levi's-Cone arrangement was known - meant that the country's most famous jean had a single, named, visitable source of cloth, a fact that became load-bearing when the plant closed: there was a somewhere for the myth to lose.

The mill town around it was the industry's social architecture in miniature: company houses, company stores, generations of families in the weave rooms, the rhythms of the looms setting the rhythms of the town. When the American denim industry offshored through the 1990s and 2000s - NAFTA first, then China's rise and the quota system's end [J63] - the towns hollowed with the mills. White Oak outlasted almost all of them, which is why its 2017 closing landed as

a national story rather than a local one: the last of a world, not the first of a loss [J14] [J15].

The relationship between the garment brand and the mill was unusually old and unusually personal by industrial standards. The "Golden Handshake" - the Levi's-Cone understanding dating to 1915 - was for decades exactly that, an understanding: Levi's took the bulk of White Oak's XX denim, Cone invested in the looms and the dye ranges to serve it, and neither side's lawyers were much troubled. The arrangement gave the 501 a single, stable cloth for most of a century, which is one reason a collector can date a pair by its fabric hand. When the industry globalised and the handshake hardened into contracts and then into sourcing spreadsheets, something more than a supply line was lost: the product stopped having a home address [J14].

White Oak's weave rooms were also a museum that worked for a living. Alongside the modern shuttleless machines, Cone kept running its old Draper X3 shuttle looms - the same model generation that had woven denim before the First World War - because the cloth they made could not be got any other way, and because the premium lines that wanted it paid the difference. When the plant closed in 2017, those looms were the assets the heritage world grieved for by serial number [J14]. The looms' scattering to collectors, small mills and one resurrected North Carolina operation is the most literal case in this book of industrial heritage being bought back from the scrapyard.

PART V - THE UNIFORM

Chapter 19 - Dude ranches and westerns

For its first fifty years the jean belonged to the man who worked in it, and the market was bounded by his wages. What changed the garment's meaning - what turned work clothes into a national costume - was not advertising but an act of imitation: the East fell in love with the West. In the 1930s, dude ranches spread across the Rocky Mountain states, offering city families a paid fortnight of playing cowboy, and the dude ranch became, in effect, a showroom. Visitors went home with boots, hats and jeans, and, more importantly, with the discovery that the garment was comfortable, hard-wearing and carried a scent of authenticity no department-store trouser possessed. Levi Strauss's first women's jeans, the 1934 Lady Levi's, were a direct answer to the women coming back from the ranches [J2].

The movies finished what the ranches began. The singing-cowboy pictures and the bigger westerns of the 1930s, 1940s and 1950s put Roy Rogers, Gene Autry and John Wayne in Levi's and Lee Riders before audiences of tens of millions, on screens where the cloth read as the natural skin of the frontier [J8]. The western was America's founding myth retailed weekly, and its costume department was Greensboro and San Francisco. This was not product placement in the modern sense; it was closer to an ethnographic claim - this is

what a real working Westerner wears - and it was believed, because it was true. The image then detached from the reality and travelled on its own. A boy in Brooklyn or Birmingham could pull on the uniform of a ranch hand and borrow, for the price of the cloth, a share of the myth.

The Second World War added a stranger chapter. Back-pocket arcuate stitching and decorative thread were cut back under wartime rationing of materials; painted-on stitching replaced sewn. Jeans went to war on the bodies of defense workers - the garment was so identified with essential labour that its sale was at points restricted to workers in war industries - and American GIs carried their off-duty jeans to Europe and the Pacific, seeding the garment's first international audience. When the boys in the photographs of liberated Rome and occupied Tokyo are wearing jeans, the garment's twentieth century as a global uniform has quietly begun.

The western's costume logic is worth a paragraph, because it is the mechanism by which a work garment became a costume and the costume became a fashion. The films did not sell jeans; they sold the West - open range, self-reliance, honest labour - and jeans arrived bundled inside the image. Roy Rogers, Gene Autry and John Wayne wore Levi's and Lee Riders because that is what the wardrobe departments knew real westerners wore [J8]. The audience then did what audiences do: they bought the visible part of the dream. It is the oldest formula in fashion and denim was its first great industrial beneficiary - aspiration sold through costume, at a price anyone could pay.

The war years layered a second meaning on top: jeans as the garment of national effort. Rationing boards treated decorative stitching and excess metal as non-essential; makers pared arcuates and hardware to wartime standards and painted what they could not sew. Women in the defense plants wore denim on the production lines - the Rosie-the-riveter image is substantially an image of women in work jeans - and the garment came out of the war with a new constituency and a new symbolism: the cloth of people who build things. When peace returned, the returning GIs and the women alike kept the habit.

The combination - Hollywood's myth and the war's proof - set up the 1950s. Jeans entered the decade as the garment of cowboys on screen and workers at home, cheap, familiar and American to the stitch. Nothing in the product had changed since 1937. Everything in its audience was about to.

The dude ranch economy deserves its footnote in the industry's history, because it was the first channel that sold jeans to people who did not work in them. The ranches of Wyoming, Montana and Arizona took in eastern families - and especially, by the 1930s, eastern women - and outfitted them for a fortnight's performance of western life; the jeans they wore home were merchandise as surely as the souvenir postcards. Levi Strauss & Co. understood the channel early, advertising in national magazines aimed at exactly the tourist who had discovered the garment on holiday. The sale was small in units and enormous in implication: it proved the garment could cross class and region on image alone, thirty years before the image became the business [J8].

Hollywood's part was bigger and blunter. The B-western assembly line - hundreds of features a year through the 1930s and 1940s - put jeans on singing cowboys, sidekicks, rustlers and sheriffs indiscriminately, and the costume departments bought what western workingmen actually wore. The films exported the garment's image worldwide at the exact moment the garment itself could not be exported: in occupied and liberated Europe after 1944, the American film was the advertisement and the GIs were the shop window, and the jean entered the European imagination as what the victors wore off duty [J8]. The postwar European jeans market - and later the Japanese one - was seeded by costume departments that never sold a pair.

Chapter 20 - The rebel

In 1953 Marlon Brando rode into a small California town on a Triumph in The Wild One, wearing jeans, a leather jacket and a cap, and in 1955 James Dean did much the same, more tenderly, in Rebel Without a Cause. The two films did for jeans what no campaign

could have: they attached the garment to the new postwar species, the teenager, and to his defining posture - refusal. The cloth's old meanings did not disappear; they were re-read. Durability became defiance, work wear became anti-formality, the cheapness of the garment became a rejection of the parents' respectability. Schools across America responded with bans, which functioned, as bans on teenagers' clothing always function, as endorsements [J8].

The industry watched a product designed not to wear out become the badge of a generation that intended to wear nothing else. The numbers followed the image: through the 1950s, jeans sales climbed from workwear niche to national staple, and the three houses - Levi's, Lee, Wrangler - raced to supply the youth market their advertising had not invented but quickly learned to court. It is one of the happy accidents of industrial history that the garment the teenagers adopted was engineered for the ranch rather than for them: jeans could survive being lived in, slept in, fought in, outgrown and handed down, and every one of those uses made them more desirable, because the evidence of living was written into the cloth in fade lines.

There is a deeper point here about how materials carry meaning. Denim did not become the rebel's cloth because of anything in its chemistry; the chemistry (white weft, ring-dyed warp) merely made it honest - it showed wear and could not pretend to be new. The cultural work of the 1950s was to make honesty of that kind legible as authenticity, and authenticity as rebellion. Once that reading existed, it never went away. Every subsequent wave - hippie, punk, grunge, normcore - has picked up the same cloth to say the same sentence: I am not dressed up.

The mechanics of the rebel reading deserve spelling out, because they were specific. The jean in 1950 was cheap, rugged, informal and American; each property flipped into its symbolic opposite. Cheapness read as contempt for status spending; ruggedness as physical fearlessness; informality as refusal of the suit; Americanness - in Europe especially - as membership in the new, the cinematic, the unbuttoned. When school boards banned jeans, they certified the reading. The garment's own marketing did not create

any of this; it followed, decades of advertising essentially re-selling to teenagers the meanings teenagers had made [J8].

It matters that the films' costume was real. Brando's jeans in The Wild One and Dean's in Rebel Without a Cause were ordinary production jeans, not designed costumes - the same 501s and Riders hanging in every Western store. The authenticity was available for purchase at any dry-goods counter, which is what made the rebellion mass-market. A boy could not ride Brando's Triumph, but he could wear Brando's trousers, and the price of admission was a working man's wages, not a fashion house's.

The era also quietly settled the garment's name. "Dungarees" faded, "jeans" won - the word of the young displacing the word of their parents' workwear counters. Language, cut and cinema moved together: by the time the 1960s began, the blue jean existed as a complete cultural object, and the industry's only remaining problem was supplying the whole world with it.

The industry's discomfort in those years is easy to forget from this distance. Jeans makers had spent eighty years selling to fathers and did not know what to do with sons; school bans and parental disapproval were bad for the respectable workwear business the companies thought they were in. The advertising record shows the hesitation: workwear imagery persisted alongside the new youth marketing into the 1960s, and the companies' own executives spoke publicly about quality and durability while the customer was buying defiance. The jean succeeded in the rebel market not because the industry understood it but because the product could not help being what the market wanted - cheap, tough, informal and already forbidden [J8].

What the rebel decade fixed permanently was the garment's age profile. Before the 1950s, jeans were worn by whoever worked; after it, they were worn by whoever was young - and the cohort that adopted them then never gave them up, carrying the garment up the age pyramid with them for the rest of the century. Every later jeans boom rode that ratchet: each generation's teenagers adopted the garment as their own, and each previous generation kept wearing it.

The two-billion-pair market of the twenty-first century is the accumulated wardrobe of seventy years of seventeen-year-olds.

Chapter 21 - The counterculture

In the 1960s the jean went from the costume of film rebels to the daily wear of an actual social movement, and the transformation shows in the garment's changing cut and decoration. The straight, high-waisted work jean of the ranch was joined by the hip-hugger and the flare; denim was embroidered, patched, painted, appliqued with flowers and peace signs, cut off into shorts and pieced into skirts and jackets. The counterculture did not just wear jeans; it worked on them, and the hand-worked, personalised jean of the late sixties is the exact inverse of the factory product - the same cloth, individually remade. At Woodstock in 1969, aerial photographs of the crowd read as a field of blue: half a million people wearing, in effect, one garment.

The political content was real but complicated. Jeans were the uniform of civil-rights organisers and student radicals in part precisely because they were working clothes: to wear denim was to claim solidarity with labour, the poor, the rural South. The cloth carried class meaning the way a flag carries national meaning, and it was read that way on both sides of the barricades. At the same time, the garment was by now a mass-market branded product manufactured at industrial scale by profitable corporations - a contradiction the wearers mostly chose not to examine. The jean could signify anti-consumerism while being consumed in record volume, and this trick - rebellion you can buy - turned out to be the most commercially valuable idea in the history of apparel.

Women's adoption, completing in these decades, changed the product itself. What had been a men's garment with a women's sideline became a unisex one, and the industry's centre of gravity shifted decisively toward fashion: fits multiplied, rises dropped and rose, and the five-pocket jean became a chassis on which styling could be rung through endless changes while the form stayed recognisable. Levi Strauss & Co. had organised an International

Division in 1965 as European and Asian demand took off [J2]. The cloth of Nimes, patented in California, was becoming the first truly global garment.

The counterculture's work on the garment is underrated as design history. Patching and embroidery turned mass jeans into one-off objects; the flare - borrowed, like so much sixties style, from naval uniform - re-drew the silhouette; the cutoff converted worn knees into summer shorts; and pieced denim - jackets, skirts, whole coats assembled from dead jeans - invented upcycling decades before the word. The jean proved to be the ideal base material for a do-it-yourself culture: cheap, tough, forgiving of amateur sewing, and improved in meaning by visible labour. The industry eventually learned to sell back factory versions of every one of these gestures, a cycle that repeats to this day.

The globalisation was as fast as the youth wave. Levi Strauss & Co. organised an International Division in 1965, and through the decade offices and factories spread across Europe and Asia as the jean became the first garment worn the same way on every continent [J2]. Local industries answered: France and Italy built their own jeans brands, Japan began the domestic production chronicled in Chapter 24, and every market read the garment through its own lens - freedom in the East, America in Europe, modernity almost everywhere.

The contradiction at the heart of the period deserves plain statement, because it never resolved. The jean was the uniform of a movement against consumer capitalism, and it was a branded product of consumer capitalism, made increasingly in the outsourced factories the movement would have condemned. The wearers handled the contradiction by ignoring it, and the industry handled it by selling harder. The result set the template for every later "ethical" wave in denim: the garment can carry anti-commercial meaning and commercial function simultaneously, in the same cloth, without strain - the strain all lands elsewhere, in the supply chain.

The women's market, consolidated in these decades, had its own prehistory worth one paragraph. Levi Strauss & Co. had made a women's line - "Lady Levi's" - as early as 1934, aimed at the dude-

ranch and western-wear customer, and women had worn men's and boys' jeans on ranches and in wartime factories long before the industry admitted them as customers. What the 1960s changed was not the wearing but the marketing: women's jeans stopped being small men's jeans and became a designed category, with its own fits, rises and, by the 1970s, its own advertising. The category's growth from an afterthought to roughly half the market is one of the quiet structural facts under the loud history of rebels and designers [J8].

The international spread ran on the same youth channel. In Britain and on the Continent the jean arrived as American import culture - music, film, the GI legacy - and local makers grew up under the American brands' shadow; in Japan it arrived with the occupation and stayed as craft; behind the Iron Curtain it arrived, when it did, as contraband. In every market the sequence repeated: the young wanted what the Americans had, the state or the establishment disapproved, and the disapproval certified the demand. The jean globalised not as a product looking for markets but as a rumour looking for supply [J2].

Chapter 22 - Jeans behind the Iron Curtain

No episode testifies to the jean's symbolic weight like its career in the Soviet Union, where a pair of trousers became contraband, currency and ideology all at once. The Soviet state made perfectly serviceable work clothes but could not, or would not, make the one garment its youth actually wanted. Western jeans - Levi's above all - entered the country in travellers' luggage and diplomatic bags, and a black market in denim grew into one of the best-documented consumer smuggling trades of the Cold War [J44]. Foreign visitors told for decades of being offered multiples of the retail price for the jeans off their legs [J44]; a 1981 UPI dispatch from Moscow recorded the demand for American-style jeans as a standing feature of Soviet street life [J54].

The state understood exactly what it was fighting. Official Soviet culture read the craze correctly as an ideological penetration - denim

as, in one historian's summary, an ideological weapon aimed at politically vulnerable youth - and answered with denunciation, with school and factory bans, and with attempts at domestic substitutes that satisfied no one [J44]. The smugglers and dealers who supplied the market, the fartsovshchiki, occupied a strange semi-criminal niche: supplying jeans could be prosecuted as economic crime, and yet the trade was so universal that the law operated as a tax rather than a deterrent. The black-market price of a pair of Levi's ran to a month's wages or more; jeans functioned, in effect, as hard currency you could wear.

The coda came in two acts, decades apart. When the Soviet Union collapsed, Levi's arrived officially, and the queues for the first Moscow store became a staple image of the era - the market finally legal. Then in 2022, after the invasion of Ukraine, Levi Strauss & Co. suspended commercial sales in Russia, and Western reporting on the withdrawal reached immediately for the old associations: the jean-smuggler era, the garment as a small emblem of the West's presence and absence [J45]. A cotton trouser had spent seventy years as an instrument of soft power, not because any government designed it to be, but because people everywhere read the same meanings into the same cloth.

The mechanics of the Soviet denim trade were an economy entire. Supply came through whoever crossed: tourists, sailors, students, diplomats, truck drivers on the Finland run. The fartsovshchiki - the black-market dealers - bought at the border hotels and sold at prices running to a month of ordinary wages or more, and the state replied with the instruments it had: anti-speculation statutes, propaganda against Western dandyism, and periodic crackdowns in which jeans dealing could be charged as economic crime [J44]. Nothing worked, because the demand was not for a garment but for what the garment certified - contact with the forbidden outside. A 1981 UPI dispatch treated Muscovites' hunger for American jeans as a standing condition, not news [J54].

The state's attempts at substitution are the episode's most instructive failure. Soviet industry could make tanks and orbital stations but could not make a convincing jean - the cloth was wrong, the cut was wrong, and in any case the point of the object was that it was not

Soviet. Economists of the late USSR sometimes use jeans as the index case of the system's consumer-goods failure: an economy unable to satisfy a demand its own ideology had made illegitimate. The denim curtain, in the phrase of the era, held better at the border than in the mind [J44].

The afterlives run both directions. Post-1991 Russia embraced the garment with the pent-up intensity of forty years - and then, in 2022, Levi Strauss & Co. suspended sales after the invasion of Ukraine, and the reporting immediately recalled the smugglers' era, the queues of 1991, and the garment's old office as a proxy for the West itself [J45]. Few products have ever been asked to carry so much geopolitics on two legs.

The scale of the phenomenon had its own metrics, informal but consistent. Western journalists stationed in Moscow treated the jeans trade as a standing beat: the going black-market price of a genuine pair - reported variously at figures running from a working month's wages upward - was quoted the way correspondents elsewhere quoted the exchange rate [J54]. Diplomats' memoirs record jeans functioning as informal currency for services money could not buy; tour guides' instructions to Western visitors warned them they would be approached and offered rubles for the trousers they were wearing. The garment had become a bearer bond with legs.

The state's own production attempts compounded the message. Soviet-made "jeans" - the domestic imitations and the licensed production that came late - answered the letter of the demand and missed its spirit entirely: the point of the garment was its foreignness, its certification that the wearer had a channel to the outside. A domestically produced copy was a pair of trousers. Economists studying the late Soviet consumer economy have used the episode to show how a system that could suppress markets could not suppress the information that markets carry - the jean was price, signal and propaganda defeat stitched into one garment [J44].

Chapter 23 - Designer denim

The next transformation inverted the garment's economics. Work jeans were cheap; the market's ceiling was set by what a working man would pay. In 1976, two things happened in New York in the same season: Gloria Vanderbilt put her name in script across the back pocket of a tight jean cut for women, and the Sasson brothers launched their own label with a jingle - "Ooh la la, Sasson" - that lodged in the national ear [J40]. The designer jean was born: the same five-pocket chassis, recut close to the body, sold at three or four times the price of the workwear original on the strength of a name and a fit. Calvin Klein followed and pushed the formula furthest, declaring that jeans are sex and the tighter they are the better they sell - and in 1980 put a fifteen-year-old Brooke Shields on television to ask America what came between her and her Calvins [J41].

The designer wave redrew the industry's map in three ways that still matter. First, it multiplied price points: jeans were no longer a single market but a ladder, and a brand's position on the ladder could be worth more than its factories. Second, it moved the centre of taste toward finish. If the jean was a fashion object, its surface was the fashion, and the 1980s became the great decade of the wash: stonewashing, then acid wash, then bleaching and distressing of every kind, with labels like Guess - founded in 1981 - building their identity on pre-faded product [J40]. Third, it exported the ladder. Jordache, Sergio Valente, Guess, and their European counterparts sold the American myth back to America and onward to the world at fashion margins [J40].

The old houses were forced to choose. Levi's chased the youth and fashion markets with uneven success and spent years out of step; Lee and Wrangler defended the middle. Meanwhile the finishing boom quietly created a new industrial layer - the garment laundry, examined in Part VI - and new costs, from the pumice mountains of stonewashing to the sandblasting workshops whose consequences appear in Part VIII. Designer denim is often told as a story about marketing. It is better understood as the moment the industry's centre of gravity moved from the durability of the cloth to the manipulation of its surface, with everything that followed for cost, waste and labour.

The designer wave was also a licensing and media machine, and its business mechanics were as new as its cuts. Gloria Vanderbilt's line, manufactured and marketed by the Murjani group, put a famous name's signature where the world could read it - across the back pocket - and sold in volumes no couture house had seen [J56]. Calvin Klein's jeans built a label into an empire on television advertising of unprecedented provocation; the 1980 Brooke Shields spots - "You know what comes between me and my Calvins? Nothing" - were denounced, banned by some stations, and sold out the jeans [J41]. Jordache, Sergio Valente and the rest of the stripe-pocket flock filled the tier behind [J40]. The discovery was general: in jeans, the name and the ad could be worth more than the factory.

The finish arms race that followed recast the product's surface as its substance. Stonewashing scaled from laundry trick to industry standard; acid wash - chlorine-loaded pumice - marbled the cloth; bleaching, distressing and sanding pushed the simulation of age to the edge of destruction [J40]. Guess, founded in 1981, built its identity on already-faded product, completing the inversion: the new jean now advertised itself as old [J40]. The wash floor described in Part VI - with its water, chemistry and labour costs - is the industrial residue of this decade's taste.

Prices stratified permanently. A work jean that had sold at a workingman's price now shared the shelf with product at three to five times the number, differentiated by signature, cut and wash; the tier structure of Part VII descends from this moment. The old houses' discomfort was the period's other legacy: Levi's, Lee and Wrangler, engineered for durability and priced for wages, spent years recalibrating to a market in which jeans were bought as fashion - bought, that is, more often, at higher prices, on faster cycles. Every jeans company since has lived between those two clocks.

The wave's financial structure was as innovative as its hemlines. The designer labels did not build factories; they built licensing and sourcing organisations, contracting production to the same belt of factories that made the work brands' volume and competing instead on image, fit and distribution. Murjani's build-out of Gloria Vanderbilt - signature on the pocket, name on the television - showed that a jeans brand could be created in a season rather than inherited

from the frontier, and Calvin Klein's campaign of 1980-81 showed that a jeans advertisement could be a national scandal and a national sell-out at once [J56] [J41]. The lesson generalised across apparel: the brand is the asset, the factory is a vendor.

The old houses' responses sorted them for the next thirty years. Levi's diversified and chased youth and fashion lines with mixed results; Lee leaned into fashion fits and women's wear; Wrangler stayed closest to its western base. All three lost share at the top of the market to the designers and learned the uncomfortable arithmetic of the new tier structure: that a company could sell fewer pairs at higher prices and make more money, but only by becoming a different kind of company - one that managed perception rather than production. The transition nearly broke all three of them, and it set up the consolidations and spin-offs that Part VII records [J12].

Chapter 24 - The Japanese thread

The most consequential adoption of the jean after America's own happened in Japan, and it began as an act of import-substitution with almost comic obstacles. Postwar Japan saw jeans on American occupiers and in American films; domestic production started when Big John - the Kojima, Okayama sewing firm Maruo Clothing - stitched the CANTON line in 1965, the first domestically sewn Japanese jeans, cut at first from imported American denim because no Japanese mill yet made the cloth [J43]. The Okayama region was not a random location: Kojima had sewn school uniforms and heavy tabi work socks for generations, and the Sanuki plain had the sewing; what it lacked was the fabric.

The fabric followed. Kurabo, an Okayama textile company, produced Japan's first domestic denim, and in Hiroshima prefecture the Kaihara company - founded in 1893 as a kasuri splashed-pattern weaver, incorporated in 1951 - turned its indigo-dyeing heritage to denim and grew into the fully integrated maker, spinning to finishing, that now holds about half the Japanese market and supplies the likes of Uniqlo [J43] [J16] [J17]. Japanese denim's difference was not novelty but rigour: mills took the American

reference cloth and executed it with a process discipline the declining American industry had stopped funding.

Then came the reversal that made Japan the custodian of the whole tradition. In the 1980s, as American mills went wide and fast and the old shuttle-loom character disappeared, Japanese collectors and makers became obsessed with exactly what was being lost: vintage Levi's, old machinery, irregular yarn, natural fading. In Osaka, a loose group of brands later styled the Osaka Five - Evisu, Fullcount, Warehouse, Denime, Studio D'Artisan - began in the late 1980s and early 1990s to reproduce vintage American jeans with fanatical fidelity [J42] [J43]. Evisu, founded in Osaka in 1991 and named for Ebisu, the god of prosperity, started as something between a workshop and a labour of love, its gull mark hand-painted on each back pocket, and it ignited a vintage-denim boom that spread worldwide [J42].

The full circle is worth stating plainly. Japan learned jeans from America, preserved the craft America abandoned, and sold it back - to America and Europe - at prices the originators never dreamed of, on the strength of shuttle looms, ring-spun yarn, rope dyeing and obsessive reproduction of the very goods White Oak had made by the mile. When White Oak finally closed in 2017 [J14], the living tradition of that cloth resided substantially in Okayama. Globalisation's usual story runs one way; denim's runs in a circle.

The soil for Japan's adoption had been prepared long before 1965. Japan had its own deep indigo tradition - aizome, the vat-dyeing craft that coloured everything from farmers' coats to samurai under-armour - and its own heavy-workwear sewing trades; the Kojima district of Kurashiki, where Big John's parent sewed, had been a centre of school-uniform and work-sock manufacture for generations [J43]. When Maruo Clothing stitched the CANTON jeans for Oishi Trading in 1965, the sewing skill was local; only the cloth was imported [J43]. The domestic cloth followed at Kurabo, and then, decisively, at Kaihara, whose 1893 origins in kasuri - an indigo ikat weave - meant the company entered denim already fluent in exactly the dyeing art denim depends on [J43] [J16].

The Osaka Five turned fluency into doctrine. In the late 1980s and early 1990s, a loose set of Osaka brands - Evisu, Fullcount, Warehouse, Denime and Studio D'Artisan - began producing jeans to vintage American specification: narrow shuttle looms, ring-spun yarn, rope dyeing, unsanforized cloth, period sewing, hand-painted details [J42]. Evisu, founded in 1991 and named for the god Ebisu, began as a detail-obsessed workshop whose seagull mark was painted by hand on every back pocket, and it caught the imagination of a Japanese fashion audience already primed by years of vintage-Levi's collecting [J42]. The boom then exported itself: through the 1990s and 2000s, "Japanese denim" became the global connoisseur's standard, and Okayama's mills - Kaihara, Kuroki, Japan Blue's own - the pilgrimage sites [J16] [J43].

The historical irony completes this book's first great circle. The country that learned jeans from American occupiers ended up conserving the technology America abandoned and selling it back at luxury prices; and the mill that White Oak's closure orphaned in 2017 had its tradition continued on looms in Fukuyama and Okayama [J14] [J16]. Material culture, like material, moves where it is valued.

The technical details of the Japanese adoption are worth the space, because they explain its later authority. The first domestic cloth - Kurabo's KD-8, woven in Kurashiki from 1965 - was made to compete with imported American denim on quality at a moment when Japanese consumers still equated imported with better; the early Japanese jeans brands fought the perception battle garment by garment. What changed the balance was not price but obsession: the collectors' market for vintage Levi's, centred in Osaka and Tokyo from the 1970s, taught a generation of Japanese makers exactly what the old cloth had been - yarn counts, dye depths, loom settings - and the mills learned to reproduce it while the American industry was busy forgetting [J42] [J43].

Kaihara's rise gave the boom its industrial base. The Fukuyama company's advantage was integration: it rope-dyed its own indigo warps on its own ranges and wove on its own looms, controlling the whole character of the cloth from dye bath to roll - the same verticality that had made Cone's name in North Carolina. By the

2000s Kaihara was supplying both the domestic reproduction brands and the quality programmes of global retailers, and holding around half of Japan's domestic denim market [J16] [J17]. The pupil's mills now set the standard the teacher's surviving mills are measured against.

Chapter 25 - The premium wave and the raw revival

The designer jean of the 1980s had put a name on the back pocket; the premium wave of the late 1990s and 2000s put a price on everything else. The template came again from Italy: Diesel, founded by Renzo Rosso in 1978, had spent two decades turning distressed denim into an international fashion business with attitude for advertising. Around 2000, Los Angeles became the capital of a new tier - Seven for All Mankind, True Religion, Citizens of Humanity, Joe's, AG - selling jeans at one hundred fifty, two hundred, then three hundred dollars on the strength of fit, fabric, finish and a recognisable pocket stitch. Department stores gave denim floor space once reserved for designer dresses; fashion magazines treated jeans as luxury goods. The five-pocket chassis had completed its climb from ranch to runway.

Underneath the premium boom ran a counter-current that mattered more in the long run: the raw and selvedge revival. Spread by internet forums and blogs - the communities that documented shrinkage, combs, whiskers and roping with entomological devotion - a generation of wearers rediscovered unwashed, unsanforized, shuttle-loomed denim and the discipline of earning one's own fades. Japanese reproduction brands were the revival's aristocracy; American and European micro-brands followed; new mills and reopened looms found buyers. The movement's economics were inverted from fast fashion's: buy one pair, wear it daily for a year before washing, repair it, keep it a decade. A garment engineered in 1873 for durability turned out to be the natural mascot of buy-less-buy-better, and the industry noticed - much of the sustainability

vocabulary examined in Part IX descends from lessons the raw community practised first as hobby.

The premium wave broke, as waves do. The 2008 financial crisis cut the legs from under two-hundred-dollar jeans; stretch fabric - the old Lycra revolution, arriving in denim at industrial scale - moved the mass market to jeggings and comfort; then athleisure's yoga pant threatened the category's daily-wear monopoly outright. Levi Strauss & Co.'s sales fell sharply from their 1990s peak; VF Corporation eventually spun off Wrangler and Lee entirely [J12]. Yet the jean absorbed each blow the way it absorbs abrasion: skinny gave way to wide and straight, comfort denim learned to look like rigid denim, and the market settled back toward its mean - enormous, global, and unkillable. What survived every cycle was not any fit or finish but the cloth itself and the sentence it lets the wearer say. Part VII takes up the business that sentence supports.

Diesel had set the premium template earlier and from outside America. Renzo Rosso founded the company in 1978 in Italy's Molvena, and through the 1980s and 1990s built it into an international brand on two pillars the later wave would copy: denim treated as a fashion canvas - distressed, washed, re-cut - and advertising with a self-aware, absurdist voice that made the brand part of the product [J61]. When Los Angeles produced its own premium cluster around 2000 - Seven for All Mankind, True Religion, Citizens of Humanity, AG, Joe's - the formula scaled: fits engineered to the body, fabric from the best mills, pocket signatures readable across a room, prices at two and three hundred dollars. Department stores gave the tier prime floorspace, and for a decade the category grew as if there were no ceiling.

The counter-movement that mattered most was happening quietly at the top of the enthusiast market. Raw and selvedge denim - unwashed, unsanforized, shuttle-loomed - spread through internet forums whose members documented their fades with archival rigour, rediscovering in practice what the wash floor had industrialised away: that a jean's finish can be earned rather than bought. The hobby's disciplines - wear daily, wash rarely, repair always - would later be rebranded by the industry itself as sustainability, but they

began as connoisseurship, and their first economics were simply the vintage market's: old jeans, well worn, worth more than new ones.

The correction came in two blows. The 2008 crisis collapsed the two-hundred-dollar tier overnight, and the survivors repriced; then stretch - elastane-core yarns, Shivers's fibre finally conquering denim [J46] - moved the mass market to comfort, and athleisure's leggings challenged the category's monopoly on daily wear. Levi Strauss & Co.'s long slide bottomed and turned on a strategy of direct retail and premium lines, returning to the stock market in March 2019, thirty-four years after going private [J62]. The jean absorbed the shocks as it always had: fits rotated, the chassis endured, and the market's floor - two billion pairs a year - never really moved [J33].

The heritage revival answered from the other direction. Levi's Vintage Clothing, the LVC line, began reproducing archival garments to obsessive tolerance - the 1947 501, the 1955 501, period cloth from named mills - and Japanese and European enthusiasts built the market [J42]. The economics inverted the mass model: small runs, high prices, scarcity as marketing, and the brand's own history as the raw material. LVC proved that a jeans company could sell its past as a premium product, and every heritage brand since has mined its archive on the same principle.

The silhouette pendulum is the fashion surface of deeper cycles. Skinny's reign, roughly 2005 to 2015, was stretch-enabled body-consciousness; the straight and wide revival after 2016 was partly taste, partly comfort culture, partly the vintage market's repricing of old cuts. Each rotation obsoletes wardrobes and factory setups alike - a skinny line's sewing allowances and a wide line's marker plans differ enough to cost money - which is why the industry watches fit cycles the way farmers watch weather. The 501's endurance through every rotation is the control in the experiment: the chassis beneath the fashion [J69].

The deeper constant is that the jean keeps absorbing each wave without dissolving. Athleisure took the comfort argument; denim answered with stretch. Vintage took the authenticity argument; denim answered with reissues and raw programs. The garment's

century-old pattern of absorbing its critics continued: whatever the decade demanded of trousers - tighter, looser, softer, harder, greener - the jean found a way to be it, in indigo, with rivets.

Los Angeles deserves its paragraph as the premium wave's production capital. The city's garment district had sewn jeans for the national brands for decades; when the premium boom came, it supplied something rarer than capacity - a complete ecosystem of pattern-makers, sample sewers, wash houses and finishers within a few blocks, in the country where the marketing happened. The premium brands' signature look - the complex, layered, hand-finished wash - was substantially a Los Angeles product, and the city's laundries charged what craftsmanship charges. The boom's bust in 2008 hit that ecosystem first and hardest, and the wash houses that survived did so by learning to serve smaller runs and faster cycles - the apprenticeship for the next era.

The raw revival's economics inverted every rule the wash era had taught. Where distressed product sold simulated age at a premium, raw denim sold no finish at all at a premium - the customer paid extra for the privilege of doing the ageing personally, over months of unwashed wear, and posted the results online for judgment. The practice looked like eccentricity and behaved like a market signal: it demonstrated a durable global minority for whom the garment's value lay in its material truth. Every subsequent "authenticity" programme in the industry - the reissues, the selvedge lines, the transparency reports - is downstream of that demonstration.

PART VI - THE FACTORY

Chapter 26 - The map of making

A pair of jeans sold in a European shop today is likely to be one of the most travelled objects in the shop. The cotton may be American, Brazilian, Indian or West African; the yarn and cloth woven in Pakistan, Turkey or China; the garment cut and sewn in Bangladesh, Vietnam, Cambodia, Egypt, Jordan or Lesotho; the wash applied there or in a specialist laundry; the whole then containerised through a hub port to a distribution centre and a shelf. Denim was one of the first apparel categories to globalise completely, because it combined huge, stable demand with a standardised product, and its supply chain is now a standing illustration of how the world trades [J8] [J33].

The geography has its capitals. Xintang, a town in Guangdong's Pearl River Delta, became known as the jeans capital of the world, its thousands of workshops and factories turning out a large share of China's - and thus the planet's - jeans [J37]. Bangladesh built the world's second-largest garment export industry substantially on denim bottoms. Pakistan's Faisalabad-Karachi corridor houses vertically integrated groups like Soorty and Artistic Milliners that spin, weave, sew and finish under one ownership [J36]. Turkey positioned itself as Europe's rapid-response denim maker, close to market and high on quality; Mexico's Torreon clothed the American

market under NAFTA's logic of proximity; Lesotho's factories, built under African trade preferences, cut jeans for American brands from Asian cloth. Vietnam rose on trade agreements and efficiency. Each node is a bet on some mix of labour cost, trade law, distance and skill.

The logic that placed all this is not mystery but arithmetic: cutting and sewing jeans is labour-intensive, labour is the largest slice of garment cost, and so the sewing migrated toward the lowest wages consistent with acceptable quality and logistics - and keeps migrating as wages rise. What the brands retained, almost without exception, was everything except the making: design, marketing, distribution, and above all the customer. The companies whose names are on the waistbands overwhelmingly do not own the factories whose names are on the shipping manifests. That separation, between who profits from a pair of jeans and who physically produces it, is the structural fact behind most of what Part VIII must describe.

One further pattern deserves note before the detail: concentration at the cloth layer. While garment sewing scattered across dozens of countries, denim milling consolidated into a relatively small club of very large producers - a handful of mills in China, Pakistan, India, Turkey and Japan supply a disproportionate share of world cloth. The reasons are capital and consistency: a dye range and a battery of looms are expensive, and buyers of commodity cloth pay for uniformity. The result is an industry shaped like an hourglass - many cotton growers at the top, many brands and retailers at the bottom, and a narrow waist of great mills in the middle [J32].

Trade law drew this map as much as wage arithmetic did. From 1974 to the end of 2004, the Multi-Fibre Arrangement and its predecessors parcelled the American and European markets into country-by-country quotas; jeans production scattered to wherever quota could be found - which is how Lesotho, Jordan, Mauritius and the Caribbean joined the supply chain. When the quotas ended on January 1, 2005, production rushed toward China, the lowest-cost integrated base, and the adjustment remade national garment sectors in a few years - a natural experiment in how much of the industry's geography was law rather than economics [J63]. Preference

programmes then rebuilt some of the scattering on new terms: AGOA for African exporters, USMCA rules for Mexico, and everything-but-arms access to Europe for the poorest producers.

The nodes specialise, and their specialisms are the industry's personality. Xintang's cluster in Guangdong turned whole towns to jeans - cloth, sewing, washing, hardware and logistics stacked within a few kilometres, at a scale no other district matched [J37]. Bangladesh's Dhaka-Gazipur belt built the world's second-largest garment export industry with denim bottoms as a mainstay. Pakistan's Faisalabad-Karachi axis runs vertically integrated groups - Soorty, Artistic Milliners, Naveena - from bale to boxed garment [J36]. Turkey's mills and factories sell speed and quality into Europe; Mexico's Torreon sold proximity to America. The jean in a rich-country shop is thus a committee decision of several national economies, assembled on the body of the garment.

The layer that stayed concentrated is the cloth, and the hourglass shape has consequences. A handful of great mills - in China, Pakistan, India, Turkey, Japan - supply a disproportionate share of world denim fabric, and their investments set the industry's technical agenda: which dye systems scale, which recycled fibres are available, which certifications exist [J32]. When Part IX's innovations spread or stall, they do so at the hourglass's waist, in a few dozen boardrooms - a fragility and a leverage point at once.

The map keeps moving, and the movements are the industry's news cycle. China's share of world garment exports peaked in the mid-2010s and has been eroding since, to Bangladesh and Vietnam above all, as Chinese wages rose and trade politics pushed buyers to diversify; the Xintang cluster itself shrank under environmental consolidation, its laundries gathered into a single policed industrial park [J37]. Bangladesh's rise made it the second garment exporter in the world; Pakistan held the vertically integrated denim niche; Turkey sold speed and quality into the European market; and Africa - Lesotho's denim-for-America factories under AGOA, Ethiopia's industrial parks - took a first real share. The jean's geography of 2026 is more plural than at any time since 1990.

What does not move is the logic. Each relocation follows the same bundle: labour cost and supply, trade access, cotton or cloth proximity, power and water, and the political stability to keep ships sailing on schedule. When any element shifts - a quota ends, a tariff lands, a river runs dry, a wage doubles - the orders move, and the factories follow, and the towns rise or empty. Reading the industry's map over fifty years is reading that equation's solutions, country by country [J63].

Chapter 27 - The garment factory

Turning cloth into jeans looks simple and is not. A jeans factory receives fabric in rolls, spreads it in layers dozens of plies high on cutting tables, and cuts the pattern pieces - legs, yokes, waistbands, pocket bags, flies, belt loops - with band knives or computer-controlled cutters. The pieces are bundled and move to the sewing floor, where the garment is assembled along a line of operators, each performing one operation: one attaches pocket bags, one sets the rivets, one runs the seat seam, one hems. A pair of jeans passes through scores of hands and dozens of machines - single-needle lockstitch, chainstitch, bartackers, rivet presses, button setters, waistbanders - and a well-run line turns out a finished pair every few minutes.

The sewing itself has its own physics. Denim is heavy and seams cross multiple plies; at the seat and fly, the needle must punch through eight or more layers of twelve-ounce cloth. Chainstitching on the waistband and hems gives the roping effect - the puckered, abraded hem edge prized on old jeans - because a chainstitched hem shrinks and wears differently from the cloth around it. Bartacks - the dense zigzag knots of thread - hold belt loops and pocket corners alongside the rivets. The five-pocket form is so standardised that a skilled operator can move between factories and countries without retraining, which is part of why the sewing moved so readily around the world.

What the floor cannot easily change is its economics. Garment sewing has resisted the automation that transformed spinning and

weaving; the limp, shifting cloth defeats robots, and the human hand remains the cheapest general-purpose manipulator of fabric ever built. Automated sewing - sewbots - exists in niches and works on simple goods, but a jean's curved seams, heavy layers and hardware have kept it mostly manual [J33]. Hence the migration logic of the previous chapter, and hence also the industry's employment profile: apparel manufacture remains one of the largest industrial employers on earth, and denim, with its high volumes and its concentration in a few producing countries, sits near the centre of that employment. Every argument about the industry - wages, unions, safety, trade policy - is ultimately an argument about the people at the machines.

The floor's choreography is worth slowing down for, because so much of the industry's social cost originates at its pace. Assembly is broken into dozens of short operations, each timed; operators are paid and lines balanced against the standard minute values of each task - attach pocket, set rivet, close inseam, hem. The jean's standardisation makes it the ideal line product: the operations never change, only the sizes and the styling, so a good line holds a rhythm of a finished pair every few minutes from start to end. Quality stations watch seams, bartacks and measurements; the rework pile is the manager's daily enemy. The system is Taylorism in pure form, and it is why the sewing of jeans could migrate anywhere a workforce could be trained to the standard - and why wages, the largest variable cost on the floor, rule the geography.

The industry's failure to automate this floor is one of manufacturing's famous limits, and it is not for want of trying. Fabric is limp, stretchy, and slippery; it shifts under handling in ways rigid materials never do, and machine vision and grippers have struggled for decades with what a human hand does thoughtlessly. Sewbots - the American firm SoftWear Automation is the emblematic effort - have cracked simple goods like T-shirts and bath mats, but a jean, with its curved seams, eight-layer intersections, hardware and heavy cloth, remains mostly beyond them [J33]. The consequence is human: hundreds of thousands of people, most of them women, earn their living sewing the world's jeans, and their wages, hours and safety are the industry's central labour question.

That question was made horrifically concrete in April 2013, when the Rana Plaza building in Savar, Bangladesh - housing five garment factories - collapsed and killed more than 1,100 workers, the deadliest disaster in garment-industry history [J64]. Rana Plaza was not a denim story alone, but denim was sewn in buildings like it, and the aftermath - the binding Accord on Fire and Building Safety, factory inspections, the slow normalisation of worker-safety as a sourcing criterion - changed the floor's governance worldwide [J64]. The jean on a shelf carries this history too: the modern factory is inspected where its predecessor was invisible, and the inspection regime was bought at an unbearable price.

The audit architecture that grew after 2013 deserves a sober paragraph, because it is both real progress and a known instrument of its own gaming. The Accord on Fire and Building Safety - binding, signed by hundreds of brands, covering more than a thousand Bangladeshi factories - put engineers into buildings and remediation onto timelines, and its model spread into national programmes and successor agreements [J64]. Alongside it runs the older system of social audits - the announced inspection, the paperwork review, the sampled interviews - whose documented failures include coached workers, double books and factories that pass on audit day and fail on every other. The honest summary of a decade of reform: the buildings are measurably safer; the economics that overloaded them are intact.

The worker's own economics complete the picture. Piece-rate and target systems set the pace; overtime is often the difference between a wage and a living; and the gender profile of the line - overwhelmingly female operators, overwhelmingly male supervision and ownership - runs through every statistic the industry produces. A pair of jeans passes through roughly two hundred human hands from bale to boxed garment; the floor's section of that journey is the one where the hands are cheapest and the standard of the work most exacting. That inversion - the most demanding work bought at the lowest price - is not an accident of the system. It is the system.

Chapter 28 - The wash floor

The most distinctive factory in the denim chain is one that barely existed before 1980: the garment laundry, whose product is age. New jeans are stiff, dark and uniform; the market wants them soft, faded and various. The wash floor closes the gap, and its history is a sequence of technologies for accelerating time.

The first was the stone. Stonewashing - tumbling jeans in industrial washers with pumice stones - emerged in the late 1970s and 1980s as an industrialised version of what a river stone does to cloth, abrading the surface evenly to a powdery fade. It consumed stones by the container-load, machines by the abrasion, and garments by the torn percentage, and it produced the defining look of a decade. Acid wash followed: pumice soaked in chlorine or potassium permanganate, tumbled nearly dry, etching high-contrast marbling into the cloth [J40]. Both were water-hungry, messy, and hard to control - and both were superseded in the 1990s and 2000s by enzymes: cellulase, a protein that digests the cotton surface, delivering the stonewashed look without the stones, in less water, with less damage and far better repeatability. The stone-washed jean of 1985 and the enzyme-washed jean of 2005 are the same aesthetic produced by geology and then by biotechnology.

Local effects came next. Hand-sanding and scraping faded specific zones - thighs, knees, seat; whiskers were ground in with emery; resin was baked into permanent creases; potassium permanganate was sprayed or sponged to bleach highlights; and in the darkest episode of the trade, compressed-air guns blasted silica sand at the cloth to abrade it fast and cheap - the sandblasting whose cost in workers' lungs is described in Part VIII [J19] [J20]. The modern wash floor increasingly replaces all of this with light and gas: computer-driven lasers burn fades, whiskers and damage into the cloth in seconds with photographic precision and no water, and ozone gas bleaches and disinfects in a closed chamber. The leading supplier of that machinery, the Spanish firm Jeanologia, built its business explicitly on eliminating water, chemicals and hand-sanding from the process. The aesthetic endpoint - jeans that look lived-in - has not changed since 1980; only the means have been progressively de-materialised, from rocks to enzymes to photons.

It is worth standing back and asking what the wash floor is, economically. It is a factory for manufacturing evidence - the appearance of wear without the wearing. This is neither fraud nor folly: the comfort of washed denim is real, the softness is real, and a customer who wants a faded jean wants it now, not after eighteen months. But an honest account must note that a large share of denim's water, chemical and energy footprint is spent simulating a process that the garment would perform by itself, for free, given time. The market prices patience at zero and its simulation at billions.

The wash floor's older tools were geological and blunt, and their costs were not only aesthetic. Pumice - the volcanic glass that floats - was mined in Turkey, Indonesia and the Mediterranean and consumed by the container load; the stones broke down to grit that went out with the wastewater, wore holes in machines and garments alike, and left laundries ankle-deep in sludge. Acid wash loaded the same stones with chlorine or potassium permanganate, burning the cloth's dye in high-contrast marbling [J40]. Both looks defined their decade; both were slow, variable and destructive, and both taught the industry that the market would pay for simulated age at almost any process cost - the lesson that later financed better tools.

The enzymatic turn of the 1990s was biotechnology arriving at the laundry. Cellulase - the enzyme by which fungi digest plant fibre - nibbles the cotton surface, loosening dye and softening hand with a fraction of the pumice's water, waste and damage; laccase and other enzymes followed for bleaching effects. The modern wash floor runs on these proteins: repeatable, controllable, gentler on machines, and certified under the industry's chemical standards. The stones stayed on in the product names - stonewash is still the look's label - long after they left the machines.

The current frontier replaces chemistry with physics. Computer-guided lasers - Jeanologia's machines are the category's emblem - burn fades, whiskers, damage and even printed patterns into the cloth in seconds, to a resolution no hand-sander can match, with no water and no consumables; ozone chambers bleach and deodorise in gas phase; e-flow and nano-bubble systems carry what chemistry remains in air rather than water [J40]. The trajectory over forty years

is a clean case study in process innovation: rocks, then proteins, then photons - each step removing water, consumables and exposure while keeping the same ancient look. The look never changed at all.

The wash recipe book is a cuisine of controlled damage, and its ingredients read like a hardware store crossed with a pharmacy: pumice and its synthetic substitutes; potassium permanganate sprayed or brushed for the bright highs; bleach for the bleeds; enzymes for the softness; resins baked in curing ovens for the permanent creases; sandpaper, grinding wheels and rotary brushes for the hand-worked effects; lasers for what the hands used to do. Each recipe is developed on a standard garment, costed per pair, timed per cycle, and then replicated across tens of thousands of units - the craft of distressing, run as a production line. The best wash developers are paid like the craftsmen they are, because the difference between a sell-out jean and a dead style is often five seconds of laser time [J40].

The labour of the old-style floor bore its own ledger, and it was paid in lungs and hands. Hand-sanding and brushing put cotton dust and dye into the air; permanganate and bleach carried their chemical exposures; and sandblasting, the fastest of the distressing tools, carried the worst of all - the story the next chapter tells in full. The modern floor's machinery - enclosed lasers, ozone cabinets, automated spray booths - is as much an occupational-health programme as a styling technology, and its adoption tracks exactly the brands' fear of the next expose [J19] [J40].

Chapter 29 - The mills today

The denim mill of the twenty-first century is a large, quiet, capital-intensive enterprise, and a short tour of the club tells most of the industry's present structure. Japan's Kaihara, grown from an 1893 kasuri weaving house into full vertical integration - its own spinning, its celebrated rope dyeing, weaving and finishing - holds about half its domestic market and supplies quality-led brands worldwide, including Uniqlo's volume program [J16] [J17]. Turkey's ISKO, part of the Sanko group, sells itself as the world's largest denim

ingredient brand, licensing its fabric names to brands the way Gore-Tex is licensed in outerwear; its compatriot Orta Anadolu, older and Istanbul-rooted, plays the same premium-ingredient game [J60]. Italy's Candiani, weaving near Milan since 1938, carries the European industry's innovation flag - the mill behind much of the sector's work on regenerative cotton, recycled fibre and lower-impact dyeing. Pakistan's Soorty and Artistic Millilers run full vertical chains from fibre to finished garment at export scale [J36].

India's place in this club is structural rather than decorative, and this book notes it without making it the subject. Arvind Limited of Ahmedabad - one of the largest denim manufacturers in the world, with denim fabric capacity on the order of one hundred million metres a year - rose with the 1980s and 1990s to supply the global brands and to anchor an Indian denim cluster that includes Nandan, Sangam and others [J35]. The fibre, the dye and the cloth have always been traded across borders; India's mills are one more proof that the industry belongs to whoever executes it well, not to any flag.

Two absences define the mill map as much as the presences. The United States, which invented the category and once wove a third of the world's denim in one town, retains only a rump: Cone Denim survives under Elevate Textiles with offshore plants after White Oak's 2017 closure, and a handful of craft mills serve the heritage niche [J14] [J15]. And the mills' own customers have changed character: where once they sold to national jeans brands, they now sell substantially to the sourcing arms of global retailers and fast fashion, which buy on price and calendar. The mill club's response has been to climb the ingredient-brand ladder - selling innovation, sustainability credentials and fabric identity, not just cloth - because cloth alone is a commodity and commodities are ground between the hourglass's two stones.

The ingredient-brand strategy deserves its own explanation, because it is the mills' answer to commoditisation. ISKO, the Turkish giant, licenses fabric platforms - named, trademarked cloths with specified performance - the way Intel sold processors: the garment brand buys not generic denim but a named ISKO fabric, and ISKO advertises to consumers over the brand's head [J60]. Orta Anadolu, Istanbul-rooted since the 1950s, plays the same game at the premium end;

Italy's Candiani, weaving near Milan since 1938, has made itself the industry's laboratory - the mill behind much of the sector's work on recycled fibre, regenerative cotton and cleaner dyeing - and sells the innovation as the product. The strategy works because of the hourglass: a concentrated mill layer can invest in identity in a way the fragmented factory layer cannot [J32].

The volume clubs anchor the supply. Pakistan's Soorty and Artistic Milliners run bale-to-box vertical operations at world scale [J36]; China's Prosperity, Advance and Foison supply the volume middle; India's cluster around Arvind of Ahmedabad - denim capacity on the order of one hundred million metres a year - ranks among the largest on earth and anchors the country's position as both a grower of the fibre and a weaver of the cloth [J35]. Japan's Kaihara, at the quality summit, holds about half its home market and supplies the quality programmes of global retailers [J16] [J17]. Between these few dozen firms flows most of the cloth for two billion pairs a year.

What the club sells, beyond cloth, is increasingly compliance and documentation: certified fibre, audited chemistry, traced dye - the paper trail the rulebook of Chapter 42 will soon make compulsory. The mill that once competed on price and shade now competes on data. That is the deepest change in the layer since the shuttle looms stopped: fabric as a documented substance, from field to roll.

The mills' customer list has quietly rewritten their product development. A generation ago the mill sold cloth to a garment maker who sold to a brand; today the brand's fabric team often specifies the cloth directly - fibre, yarn, dye, weave, finish - and the garment maker merely buys it on instruction. The result is that the mill's real design conversation runs with the brand, and the largest mills maintain fabric libraries, trend presentations and co-development programmes that look suspiciously like fashion businesses. ISKO's named fabric platforms and Candiani's innovation-led premium positioning are the visible edge of a structural shift: the cloth layer of the industry learned to speak brand [J60].

The capital structure underneath explains the consolidation. A competitive modern denim mill - rope-dyeing ranges, wide high-

speed looms by the hundred, finishing lines, wastewater plant - is a nine-figure investment with returns measured in decades, in a market where the customer can shift orders across borders in a season. The survivors are therefore the integrated, the specialised, or the protected: the vertically complete groups of Pakistan and India, the quality specialists of Japan and Italy and Turkey, the scale leaders of China. Everyone else was shaken out in the 1998-2008 decade, and the hourglass waist of Chapter 26 is what was left standing [J32].

PART VII - THE BUSINESS

Chapter 30 - Levi Strauss & Co. today

The company that began with a sixty-eight-dollar patent fee is now a publicly traded global apparel business, and its current shape says much about the industry it created. Levi Strauss & Co. reported net revenues of about 6.4 billion US dollars for its 2024 fiscal year, selling products in roughly 120 countries through a network of about 3,400 stores and shop-in-shops as well as wholesale and online channels [J13]. The 501 remains the spine of the enterprise a hundred and thirty-five years after the lot number was assigned, and the company's strategy documents treat it as such: a single product line that functions simultaneously as heritage asset, volume seller and brand identity.

The path here was not straight. The firm stayed family-controlled for most of its life, went public in 1971, was taken private again in a 1985 leveraged buyout, carried heavy debt for years, over-expanded, missed the premium and stretch turns, and saw sales fall from an early-1990s peak above seven billion dollars to near four billion in the early 2000s. Recovery came through the two moves the industry now treats as standard: going direct - retail stores and e-commerce, where the customer and the margin both live - and going up, with premium lines and collaborations above the core product. The company returned to the stock market in 2019. Its recent results

show the shape of the modern business: direct-to-consumer sales approaching half of revenue, women's lines growing faster than the historic men's core, and a wholesale channel that still supplies the world's department stores [J13].

Two features of the company's record deserve a place in a book about the material rather than the stock. It was early among apparel multinationals to put a written code of conduct on its contractors: its Terms of Engagement, launched in 1991, were the first comprehensive supplier code in the industry, setting labour and environmental standards for contract factories [J2]. And it has put its own product under the microscope: the company's 2015 life-cycle assessment of a pair of 501s - the water, carbon and chemistry ledger used throughout Part VIII - remains one of the most-cited product environmental studies in apparel [J9]. Neither fact absolves an industry of its costs; both show where some of the tools for reducing them were first drafted.

The modern company's shape would puzzle its founder: a portfolio organised around the Levi's brand but reaching from Dockers' khakis to the value lines sold through mass retailers; a distribution network spanning some 50,000 doors in over a hundred countries; and a deliberate, expensive pivot from wholesale dependence toward its own stores and website, whose direct sales approached half of revenue by the middle of the 2020s. The 2019 return to the stock market - the second listing in the company's history, thirty-four years after the family took it private - priced all of that: the brand's durability, the direct-channel buildout, and the bet that a 170-year-old garment could still be grown [J62] [J13].

The financial profile sets the company's strategic weather. Fiscal 2024 net revenues were about 6.4 billion dollars [J13]; gross margins near sixty percent belong to the brand economy, not the garment economy - the difference between the two being spent on the advertising, stores and systems that keep the name worth paying for. The company's own lifecycle work - it commissioned the first apparel LCAs of their kind and published them - belongs to the same brand logic: the jeans maker that sells durability benefits from measuring it [J9]. In Levi's case the mythology and the metrics turned out to be the same asset.

Chapter 31 - Kontoor and the VF story

The second house of American denim is now a company most consumers have never heard of, which is exactly how the modern apparel industry likes it. Kontoor Brands, listed on the New York Stock Exchange since its 2019 separation from VF Corporation, owns Wrangler and Lee - the two labels that with Levi's make up the American canon - and reported revenue of 2.61 billion dollars for 2024, with a reported gross margin of 44.5 per cent [J12]. Its arc is the corporate version of the industry's: Wrangler's parent Blue Bell was bought by VF in 1986, joining H.D. Lee inside what had begun as a glove maker called Vanity Fair Mills; VF grew into one of the world's largest apparel groups; and when the group's centre of gravity moved to outdoor and active brands, the jeans business was cut loose to stand on its own [J8] [J12].

Kontoor's brands occupy the middle of the market deliberately: Wrangler as the western and work anchor - still the official jean of professional rodeo [J11] - and Lee as the everyday mainstream line, with international and workwear businesses alongside. The company's own communications emphasise what the middle of the denim market competes on now: not heritage alone but execution - distribution through the great retail chains, cost discipline, and a sustainability program that its Wrangler brand has used to fund some of the industry's most public process innovation, including the foam-dyeing launch described in Part IX [J18].

The lesson of the VF-to-Kontoor story is about what kind of business jeans are. Inside a diversified group, denim was the slow, mature division whose capital could be better used elsewhere; on its own, the same business is a solid, cash-generative franchise with two of the most durable brand names in clothing. Jeans are not a growth industry in the rich world - they are an annuity, a category whose demand renews itself with every wardrobe and every generation, and whose profits flow to whoever manages an old product with current discipline.

Kontoor's numbers give the second American pole its scale: fiscal 2024 revenue of about 2.6 billion dollars across Wrangler and Lee, with Wrangler the larger and Lee the more fashion-leaning [J12].

The spin-off's logic was portfolio discipline - VF kept the outdoor and athletic growth stories, and the jeans business got its own management, its own balance sheet and its own capital-allocation case to make. What Kontoor sells investors is not growth but durability: the mid-market American jeans business throws off cash, buys back shares, and defends a customer who shops by fit and habit rather than by campaign. It is the industry's value stock, and proud of it.

The corporate archaeology under Kontoor records the whole century. Blue Bell's overalls became Wrangler; H.D. Lee's workwear became the Lee empire; VF - itself a Pennsylvania glove company turned apparel conglomerate - assembled both by acquisition in 1969 and 1986 respectively, ran them as its jeanswear coalitions, and then spun them out in 2019 when the conglomerate model fell from fashion. Each era's ownership structure mirrored that era's theory of the business: independence when jeans were a trade, conglomerate when they were a brand portfolio, focus when the market demanded accountability. The jeans underneath barely noticed; that is rather the point of the business [J11] [J12].

Chapter 32 - The market

How large is the business of jeans? The honest answer is a range, because market-research houses measure it differently, but the orders of magnitude are firm. A widely cited industry estimate values the global denim jeans market at about 85.4 billion US dollars in 2024, with a forecast rise to about 121.8 billion by 2030 - a compound growth rate around six per cent a year, the forecast being a projection, not a fact [J31]. The fabric beneath the garments is separately estimated at about 17.3 billion dollars in 2024, forecast to reach about 21 billion by 2030 [J32]. In units, the figures most often quoted across industry and institutional sources put annual production at around two billion pairs a year [J33] [J34]. Two billion pairs is roughly one new pair every year for every fourth person on earth, and it makes the jean a plausible candidate for the single most-produced garment design in history.

The market's structure is a stack of tiers that barely touch. At the base sit private-label and value jeans - supermarket and chain-store product made to a price. Above them the volume brands: the three American houses, plus the global casual retailers - Inditex's Zara, H&M, Fast Retailing's Uniqlo - for whom denim is one department among many, bought from the big mills and sold on calendar. Above them the premium and designer tier, where the product is fit, finish and name. And at the apex, small by volume and loud by influence, the heritage, selvedge and reproduction niche described in Part V. A single factory in Bangladesh may sew for several tiers at once on different days; a single mill may supply cloth up and down the ladder; the tiers are marketing, not machinery.

Demand's geography has been rotating. North America remains the largest market by value in the common estimates [J31], but the growth is in Asia, where rising incomes keep adding first-time buyers by the tens of millions. Denim's history suggests the category absorbs change rather than being displaced by it: the jean has now survived the leisure suit, the tracksuit, cargo pants, the yoga pant and the remote-work sweatpant, and each challenger became, in time, another thing worn with jeans. The business risk that executives actually worry about is not that the world stops wearing jeans but that the world's wardrobes are full: in mature markets, growth means persuading owners of seven pairs to want an eighth [J8].

The premium tier's unit economics explain its persistence. At a retail price of two hundred dollars, the jean's physical cost - cloth, making, wash, hardware - is a minority of the ticket; the rest is brand, retail margin and the fit laboratory. The tier therefore lives or dies on differentiation the customer can feel and read: Japanese or Italian cloth, a signature pocket, a fit with a name, a store or a website with a voice. When differentiation fails, the tier has nowhere to hide, because the mass market's thirty-dollar jean has become very good - the same mills, often the same cloth constructions, at a tenth of the price [J32]. The premium jean sells the last increment of quality at the first increment's price multiple, and its customers know it and pay anyway - that is the business.

Denimheads built the tier's conscience and its best marketing channel. The online communities - forums first, then Reddit and

Instagram - standardised connoisseurship: fade documentation, mill pedigrees, fabric weights, contest wear that turned a pair of raw jeans into a two-year project. Brands learned to serve them with limited runs, collaboration cloths, and retail spaces built like clubhouses; Nudie's repair promise [J66] and the Japanese brands' workshop aesthetic [J42] are products of this culture. The enthusiast market is small in units and large in influence: it set the taste that the sustainability era would later claim as its own.

The tier's geography is the industry inverted. Its cloth comes from Japan and Italy rather than the volume mills; its making clusters in Los Angeles, Okayama and small European workshops rather than the giant belts; its distribution runs through specialty stores and direct channels rather than department floors. It is, in miniature, an alternative denim industry - one that answers the question the volume industry cannot: what does the jean look like when price is not the first constraint? The answer - heavier, slower, repaired, documented - increasingly leaks back down the tiers.

Between the poles sits the mainstream brand stack the reader knows: Levi's at the centre with its tiered lines, Wrangler and Lee under Kontoor - the 2019 spin-off that separated VF Corporation's jeans business into its own public company [J12] - Diesel at the fashion edge [J61], and beneath them the licensed and private-label volume. The stack is stable because each tier defends a different claim - authenticity, fashion, value - and the claims rarely collide head-on. Competition happens within tiers, and the tiers are maintained as carefully as the seams.

The fast-fashion machine's mechanics are worth precision, because "fast fashion" is often used as a slogan where it is in fact a production system. Its elements: design cycles measured in weeks rather than seasons, enabled by data from stores flowing back to designers in near-real-time; small initial orders with rapid replenishment of what sells; sourcing spread across a bench of competing factories held to short lead times; and prices set low enough that the garment is bought casually and discarded casually. Applied to denim - a category built on durability - the system produced a genuine contradiction: a jean designed to be worn briefly, washed rarely, and replaced often [J68].

The supply chain bent to the clock. Speed favoured proximity for the fastest cycles - Turkey and North Africa for Europe, Mexico and Central America for the United States - while the volume base stayed in Asia; the same garment might exist in both a slow cheap version and a fast near one. The wash floor became a styling department: fast fashion's appetite for novelty multiplied the wash, print, embroidery and distress variations, and the finishing costs of Part VI migrated from brand laundries onto the factories, squeezed into the price. The two-billion-pair floor [J33] is substantially this system's output.

The reckoning arrived from several directions at once. Environmental accounting - the water, chemistry and carbon of Part VI - attached itself to the sector's name; the Kantamanto studies quantified where the volume ends up [J68]; and regulators, chronicled in Chapter 42, began drafting rules that price the throughput model's externalities into it. The system's response so far is adaptation rather than retreat: recycled content in the blends, resale pilots, durability claims in the marketing. Whether the clock itself can slow while the model stands is this decade's open question.

The private-label tier is the industry's silent majority and its least examined economy. Supermarket and hypermarket jeans, fast-fashion basics, and the store brands of mass chains are made in the same belts as the branded volume - often the same factories - with the brand's markup removed and the retailer's scale substituted. The tier's existence disciplines everyone above it: it sets the price floor against which a hundred-dollar jean must justify itself, and it absorbs the volume that keeps the giant factories balanced between brand seasons. When this book says two billion pairs [J33], much of the count is this tier, wearing names the world will never read twice.

The tier also concentrates the industry's ethical exposure, because its economics are the tightest. A retailer squeezing cents from a five-dollar wholesale jean transmits the squeeze to the factory, and the factory to the worker and the wash floor; the audit regimes that followed Rana Plaza [J64] are disproportionately the architecture of this tier, because this is where the pressure lives. The same tier, though, is where recycled fibre and cleaner chemistry reach the most bodies per dollar when they do arrive - the fast-fashion giants'

sustainability programs, whatever their limits, move material at a scale the premium tier cannot touch.

Both statements are true, and holding them together is the honest way to read the mass market: it is where the industry's harms are densest and where its improvements travel furthest. The jean at the bottom of the market is the same object as the one at the top - twill, indigo, rivets - and the distance between them is the book's recurring subject: an industry that makes one thing at every possible price.

The forecast numbers that circulate in the trade deserve handling with the care this book promised at the start. Market-research houses' estimates of the global jeans market cluster in the eighty-to-ninety-billion-dollar range for the mid-2020s, with projections past a hundred billion by 2030 - one widely cited series - TechSci Research's market model - values the 2024 market at about 85.4 billion dollars and projects roughly 121.8 billion by 2030, a compound growth of about six percent [J31]. These are forecasts and modelled estimates, not measurements: the houses define the category differently (jeans only or denim apparel broadly, retail or wholesale value), and the numbers should be read as an order of magnitude with a growth story attached, not as audited fact. The denim fabric market beneath them is estimated separately, in the high-teens of billions, growing toward the low twenties [J34].

The more solid anchor is units, because units are countable. The oft-quoted figure of about two billion pairs sold per year - used, among others, by the shipping industry that moves them - implies a garment bought roughly once every four years by every human on earth, or, more realistically, bought constantly by the third of humanity that wears them [J33]. Against that base, the growth stories of the forecasters - Asia's rise, premiumisation, women's and children's categories - are arguments about mix and price rather than about whether the world will keep wearing jeans. On that question the market has been giving the same answer for seventy years.

Chapter 33 - The price of a pair

What does a pair of jeans cost to make, and where does the retail price go? Precise ledgers are proprietary, but the structure is stable enough to state. At the factory gate in a major producing country, a standard five-pocket jean - cloth, trim, cutting, sewing, washing, packing - leaves at a price in the single digits of dollars. Within that: the fabric is the largest material cost, roughly half; sewing labour is significant but modest per pair because a line produces fast; the wash adds from little to more than the sewing, depending on how much simulated age the product specification demands. Freight, duty and the importer's margin add their layers; the brand's own costs - design, marketing, retail rent or platform fees - and its profit add theirs. A pair retailed at one hundred dollars in the rich world commonly carries a factory cost of well under ten.

The arithmetic explains three features of the industry at a stroke. It explains the migration of sewing: when labour is a large share of a small gate price, wage differences between countries decide locations. It explains the wash floor's intensity: the difference between a ten-dollar jean and a sixty-dollar jean is mostly finish, and finish is water, chemicals and labour. And it explains the tier structure: the cost of making a premium jean is only modestly above the cost of making a basic one - better cloth, more careful sewing, slower laundry - while the price is multiples. What the premium customer buys is mostly not additional material but design, identity and scarcity, and the industry's profits concentrate accordingly in brands and retail rather than in farms, mills or factories.

This is the standard apparel pattern, but denim displays it in an especially pure form, because the underlying product has been technologically stable for a century and a half. Nothing in a 2026 jean is meaningfully harder to make than in a 1976 one. All the value added since has been added in story, surface and channel - which is why the chapters on the industry's future are not about a better jean in the old sense, but about the two genuine new frontiers: how the garment is made without its current environmental cost, and how its very long useful life can itself become a business.

The price ladder's rungs are worth naming with real numbers, because the tier structure is the market's true map. At the floor: supermarket and unbranded jeans at ten to twenty-five dollars, made

to a cost target first and a design second. The mass branded tier - the entry lines of the big houses and the fast-fashion chains - runs roughly twenty-five to sixty. The core American brands sit at sixty to a hundred. Premium begins around a hundred and runs to two-fifty; the Japanese and artisanal reproduction market starts there and climbs past four hundred; and designer-label denim, where the jean is a logo delivery device, prices wherever the house chooses. The fabric, at its fanciest, accounts for a few dollars of the difference. The rest is fit, finish, brand and story [J32].

Cost engineering at the floor deserves its own respect. Hitting a ten-dollar retail price means a garment cost of perhaps two to three dollars, which means fabric bought at the cheapest workable quality, sewing at the fastest standard minute values the market offers, minimal washing, and hardware simplified to the legal minimum - and yet the result is recognisably, functionally a pair of jeans, durable enough to outlast its fashion. That a garment with the jean's specification can be delivered at that price at all is a genuine industrial achievement; the ethical question of how it is achieved is this book's Part VIII, and the two statements belong in the same sentence.

PART VIII - THE COST

Chapter 34 - Water

The number most people have heard about jeans is a water number, and it is worth being careful with it. The widely repeated figure - popularised by the United Nations in 2019 - is that it takes about 7,500 litres of water to make a single pair of jeans, as much as one person drinks in seven years [J7]. The same UN system's more recent technical statement is less quotable and more accurate: in average conditions, producing a pair takes around 3,000 to 4,000 litres, with the most efficient processes near 2,000 and the least efficient above 10,000 [J6]. Levi Strauss & Co.'s own product-level assessment put the full life cycle of a pair of 501s - field to wardrobe - at nearly 3,800 litres [J9]. The honest summary is that a pair of jeans carries a water ledger measured in the thousands of litres, varying hugely with where and how the cotton grew and the cloth was processed, and that the popular seven-and-a-half-thousand is the high end of a wide band, not its centre.

Where the ledger sits matters more than its total. In the Levi's assessment, fibre production - the cotton field - accounts for about 68 per cent of the water, with consumer washing at about 23 per cent and fabric production and garment manufacture making up the rest [J9]. The dye range, the wash floor and the laundry are visible, concentrated and blameworthy; the field is diffuse and far away, and

it is the largest line by far. This distribution dictates the remedies: better irrigation and rain-fed sourcing in cotton, recycled fibre that skips the field entirely, and - the remedy the industry can neither control nor stop recommending - washing jeans less. Levi's found American consumers washing after about two wears and calculated that moving to ten wears would cut the jeans' water and climate impact by roughly three-quarters [J9].

Context completes the picture. Jeans are the emblem, not the exception: the UN estimates the fashion industry as a whole uses on the order of 93 billion cubic metres of water a year [J7], and the garment in the indictment is denim because denim is the garment everyone owns. The material thinking this book applies in every chapter gives the right final framing: a pair of jeans is mostly water held briefly in the shape of cloth - rain and irrigation, vat water, wash water, laundry water - and the industry's water problem is the sum of decisions distributed from the field to the owner's washing machine. Every stage now has a known technical improvement; what has been missing is a reason to pay for them. Part IX describes the reasons arriving.

The Aral Sea is the ledger's monument. Soviet planners diverted the Amu Darya and Syr Darya to irrigate the cotton desert, and over decades the sea - once the world's fourth-largest lake - shrank to a fraction of itself, leaving salt flats, poisoned dust, ruined fisheries and a cotton monoculture whose economics were as broken as its ecology [J67]. It is the largest garment-linked environmental disaster on earth, and it was wrought substantially for the fibre of cheap clothes, jeans among them. The lesson generalises: fibre agriculture is land and water policy, and the jean wears the consequences of both.

The consumer end of the ledger is the simplest and the most resisted. Levi's lifecycle work found the washing machine and dryer to be a major share of the garment's lifetime water and energy, and the industry's care campaigns - wash less, wash cold, line dry - ask the customer to finish the sustainability the factory started [J9]. It is a strange inversion: after a century of selling the jean as indestructible, the industry now sells not washing it. The denimheads, washing

rarely and mending always, turn out to have been the environmental avant-garde all along.

The numbers behind the headline repay a careful reading, because the two most-quoted water figures measure different things. The Levi Strauss & Co. lifecycle assessment - the apparel industry's pioneering product LCA, first run in 2007 and repeated with a 501 in 2015 - found nearly 3,800 litres of water consumed across a pair's life, with fibre production responsible for about 68 percent of it and consumer care for about 23 percent; on the climate side, consumer care (largely the dryer) and fabric production were the largest shares [J9]. The UN's 7,500-litre figure - the one that made headlines - is a fuller accounting on a different basis [J7]. Neither number is wrong; they are different ledgers. What they agree on is the shape: the cotton field and the owner's laundry room dominate, and the factory in between - for all its steaming drums - is not the main account.

The policy consequence of that shape is significant and often missed. A brand that wants to cut the jean's water ledger cannot get there with factory plumbing alone: it must change the cotton (better irrigation, different varieties, recycled fibre) and the customer (fewer, colder washes) - the two ends of the chain the brand controls least. Levi's response ran exactly that way - Better Cotton sourcing upstream, care-label and consumer campaigns downstream [J9]. The jean's water problem is, in the end, agriculture and habit, with the dye house in the middle doing what it can.

Chapter 35 - Carbon and chemistry

The climate ledger of a pair of jeans is dominated by energy, and it too is distributed. The Levi's life-cycle study put a 501's total climate impact at 33.4 kilograms of CO2 equivalent across its life - with fabric production and consumer care (washing and especially machine drying) the largest shares, and the fibre's cultivation contributing through fertiliser, machinery and irrigation energy [J9]. Thirty-three kilograms is the tailpipe emission of about 130 kilometres of driving an ordinary petrol car; multiplied by two billion pairs a year, the category's annual addition is measured in the

tens of millions of tonnes, before counting the wear-phase washing of the billions of pairs already in wardrobes. Apparel and footwear together are estimated at between 2 and 8 per cent of global greenhouse-gas emissions [J6].

The chemistry ledger is older and uglier. Conventional synthetic indigo is manufactured from petrochemical feedstocks through intermediates that include aniline; the reduction step consumes sodium dithionite and caustic soda and discharges their decomposition products; sulphur-dye blacks add sulphide loads; and the finishing sector historically used chlorine bleach, potassium permanganate and a suite of resins and softeners. Indigo itself is comparatively kind - poorly soluble, not acutely toxic, fixed mechanically rather than by reaction - which is precisely why the load falls on its auxiliaries: the reducing agents, the alkali, and the unfixed pigment that turns effluent visibly blue. New entrants attacking the problem put the feedstock case bluntly: the bio-indigo company Huue notes that conventional production embeds dozens of kilograms of petroleum in each kilogram of dye [J29], and the natural-indigo growers of Stony Creek Colors argue that much dye sold as natural is quietly adulterated with the synthetic product and its aniline baggage [J28].

Then there is what the finished garment sheds. Stretch denim - a large and growing share of the market - contains elastane, and every synthetic-cotton blend sheds microfibres in the wash; textiles as a class account for an estimated 9 per cent of the microplastics entering the oceans annually [J6]. The jean's chemistry problem, in short, runs from the oil well to the laundry drain, and it is the least visible of its costs: rivers can be photographed blue, but sulphate loads, carbon and microfibres cannot. Regulation is now arriving to make them legible, as Part IX records.

The carbon ledger's arithmetic follows energy, and it follows it through the whole chain. Ginning, spinning, weaving and dyeing are all powered processes; the wash floor heats water and runs dryers; the garment is shipped, trucked and flown; and then the consumer washes and - decisively - tumble-dries it for years. The LCA's finding that consumer care rivals production on the climate account is the uncomfortable one, because it says the industry's footprint is

partly owned by its customers' laundry habits [J9]. Hence the care campaigns, the "wash less" messaging, and the strange spectacle of a clothing company telling people to use its product less.

The chemistry ledger's modern management deserves its due alongside its history. Restricted-substances lists, the ZDHC coalition's manufacturing guidelines, third-party certifications of dyestuffs, and wastewater testing regimes now govern the serious end of the industry, and the dyestuff makers themselves have reformulated: pre-reduced indigo, aniline-free indigo, liquid sulphur dyes with lower sulphide [J28] [J29]. The gap is not the existence of clean chemistry but its universal application - the difference between what the top tier's mills run and what the subcontracted bottom still discharges. Once again: the technology is solved; the governance is not.

Chapter 36 - Blue rivers

There are places where denim's cost can be seen from a boat. The town of Xintang in Guangdong - the self-styled jeans capital, whose factories and workshops at their peak produced an enormous share of the world's jeans - became in the 2000s and 2010s the standard exhibit of the industry's pollution: rivers running dark blue and black with dye-house and laundry discharge, workers processing denim in clouds of dust and chemical spray, villages downstream of the world's wardrobe [J37] [J38]. CNN visited in 2010 and documented the water; Al Jazeera's 101 East did the same for the labour in 2015; Greenpeace's Dirty Laundry investigations traced the effluent of suppliers serving global brands and forced the issue into boardrooms [J38] [J37] [J39]. The documentary RiverBlue carried the images worldwide, and the phrase "there is a pair of jeans behind this river" became a campaigner's shorthand.

The mechanics of the pollution are exactly the chemistry of Part II industrialised without a treatment plant. Indigo is applied at low fixation - much of the pigment never binds and washes out as suspended blue solids; dithionite reduction leaves sulphite and sulphate; caustic baths raise pH; desizing washes starch and

synthetic size into the stream; the laundry adds pumice dust, enzymes, bleach and permanganate. None of this is exotic or unavoidable: each load has a known treatment, and the modern export factories of the big vertical groups run treatment plants that make their outflow dull and legal. The Xintang images came from the industry's unmanaged edge - thousands of small workshops racing on price, in a jurisdiction racing for growth - and the lesson generalises: denim's environmental record is set less by its technology than by the enforcement environment of wherever it happens to be made.

That is why the campaigners' pressure moved the way it did - not primarily at factories, which respond to inspectors, but at brands, which respond to reputation. Greenpeace's 2011 Detox campaign extracted public commitments from the world's largest apparel companies to zero discharge of hazardous chemicals across their supply chains, and the industry built shared chemical-management standards under the ZDHC umbrella. The blue rivers of the 2010s pushed the sector into its first genuinely collective environmental regime. Whether the regime has teeth where it matters - in the second and third tiers of subcontracting, where the cameras do not go - is an open question, and one of the honest uncertainties this book carries into its final part.

The chemistry ledger begins where Chapter 3 left off: the dye house's indigo and sulphur systems, their reducing agents and salts, and the wastewater that carries what the yarn will not hold. To this the wash floor adds its own inventory - permanganate for the bright fades, chlorine for the bleaches, resins for permanent creases, enzymes and softeners and fixatives - and the sum is one of the most chemically intensive finishing regimes in apparel [J6]. The regulation of it is comparatively recent: restricted-substance lists, wastewater standards, and programmes like ZDHC - the industry coalition's zero-discharge roadmap - date mostly from the 2010s, which is to say that for most of the jean's history, what came out of the dye house went into the nearest river unexamined.

Xintang is the ledger's best-documented page. Greenpeace's 2010 investigation of the Guangdong denim towns found rivers running blue and black with dye-house and laundry discharge, heavy metals

and persistent chemicals in the sediments, and a local population living with the effluent of the world's jeans [J37]. The reporting forced the cluster's first real cleanup - consolidated treatment plants, relocated factories, closed laundries - and became the standard reference for what concentrated denim production does to water when nobody prices the river. Similar files exist for Dhaka's Buriganga and the Mexican laundry belts; the pattern is the cluster's shadow, everywhere the same shape.

The remediation toolkit now exists and is documented in Part IX - foam and laser finishing, closed-loop water, cleaner reducing agents - so the chemistry ledger is increasingly a governance problem rather than a technical one: the clean technologies are available, and their adoption tracks inspection, price and law. That is the through-line of every environmental chapter in this book. The jean's harms are known, mapped and increasingly optional; the remaining question is who pays to make them optional everywhere.

The Buriganga at Dhaka and the laundry towns of Mexico's Tehuacan valley tell the same story with local details. In Dhaka, the tannery and textile effluent turned the river that defines the city's edge into something its own residents describe in the past tense; in Tehuacan, the jeans laundries that arrived with NAFTA discharged the blues and permanganates of the wash floor into a valley of orchards, and the aquifer itself changed colour in the telling of local campaigners. The pattern is the cluster's shadow: wherever the industry concentrates fast and regulation arrives late, the water keeps the books [J37] [J38].

It is worth being precise about what improved and what did not, because both halves are true. Following the investigations and the pressure they created, the serious end of the industry built real wastewater treatment, consolidated the worst clusters, adopted the chemical standards of Chapter 35, and learned to test and publish; the Xintang laundries today operate under constraints unthinkable in 2010 [J37]. And the volume did not shrink - it moved and grew - so the absolute ledger of the industry is argued about honestly by honest people. The river in any given town can be cleaner while the world's total blue discharge rises. Both observations belong in the same report.

Chapter 37 - Sandblasting

The denim industry's worst single labour scandal is neither a collapse nor a fire. It is a look. In the mid-2000s, the fashion for a worn, blasted finish met a fast and cheap way to produce it: workers in small workshops aimed compressed-air guns loaded with silica sand at jeans hung in booths, abrading the cloth in minutes. The booths filled with respirable silica dust; the workers, mostly very young men, breathed it. Silicosis - the ancient, incurable scarring disease of miners and sandblasters - followed with terrifying speed.

The medical record is stark. Turkish physicians reported in the European Respiratory Journal on a case series admitted between 2004 and 2006: sixteen young men from small sandblasting workshops, mean age twenty-three, mean exposure just three years; the first two died, and most of the rest were left with permanent disease [J19]. A later Turkish review records the shape of the epidemic that followed: silicosis re-emerging in 2004 among denim sandblasters, workers starting as teenagers, and the practice's migration, after Turkey banned silica sandblasting in 2009, to other garment countries with weaker enforcement [J20]. Campaigners at Labour Behind the Label documented dozens of deaths and argued, correctly, that every case was a purchased effect: the faded jean on the shelf was the disease's transmission vector [J21].

The industry response is the episode's instructive half. Once the link was public, brands banned sandblasting in their supply chains one after another - Levi Strauss & Co. and H&M announced their ban in 2010, followed across the sector - and the finishing technology shifted decisively to the alternatives that could mimic the look without the dust: laser abrasion, ozone, hand-scraping with extraction, enzyme fades. The look survived; the method died, at least on paper and at least in audited supply chains. The audit qualification is the honest ending. Subcontracted finishing is exactly the kind of work that slips to the informal edge, and the review literature is blunt that the practice moved rather than vanished [J20]. Sandblasting is denim's clearest lesson in where the true cost of a cheap effect lands when the buyer is far away and the worker is

young: in the lungs, within three years, for the difference of a few cents a pair.

The sandblasting story deserves its full telling because it is the industry's clearest case of a known harm traded for a look. Silica sand, fired at denim under pressure, abrades the surface into the soft, worn, pale finish the market wanted; the operator, breathing the dust, inhales crystalline silica, and silicosis - fibrotic, progressive, untreatable - follows within years rather than the decades of mine exposure. Turkish researchers documented the outbreak among denim sandblasters in the 2000s: young men, a few years in the trade, lungs gone; dozens dead [J18]. The Turkish state banned the practice in 2009 [J19]; the Killer Jeans campaign and the Clean Clothes network pushed the ban through the brands, most of which signed on [J20]. The technique migrated to less-guarded jurisdictions before the bans caught up - the lesson that prohibition without supply-chain reach merely exports the exposure.

The replacement technologies - laser abrasion, ozone, hand-scraping with extraction, enzyme fading - now deliver the same looks without the dust, and the industry's largest laundry groups run sand-free floors as policy [J40]. The episode's deeper lesson is about visibility: the harm lived two tiers down the supply chain, in subcontracted workshops the brands did not own and often did not know, and it surfaced only when doctors named the disease and campaigners named the buyers. Every subsequent supply-chain transparency regime in this book is, in part, the institutionalisation of that naming.

The worker-safety file does not end with silica. Fire and building safety - Rana Plaza's subject [J64] - chemical handling on the wash floor, machine guarding on the sewing line, and the wages-and-hours questions of Chapter 27 all belong to the same ledger, and all improved most where they became conditions of purchase. The jean's social history, like its environmental one, runs on the same engine: visibility, then standards, then price. The order matters. Nothing in the garment's 170 years suggests the sequence runs itself.

The medical papers that broke the story read with the cold clarity of catastrophe. Physicians in Turkey's denim towns began seeing young men - workers in their twenties and thirties - with the breathlessness

and shadowed radiographs of a disease that belongs to old miners; the case series published in the European Respiratory Journal and elsewhere named the occupation plainly: denim sandblasting, a few years of exposure, silicosis [J18]. The pathology is simple and final: respirable crystalline silica, scarred lung, no cure. Follow-up reporting counted the dead by the dozen in a single region, and the true toll in the informal workshops was never countable at all [J20].

The aftermath became the template for how the industry handles its scandals at best. Turkey banned garment sandblasting in 2009 [J19]; the Killer Jeans campaign pushed the ban brand by brand until most major buyers had signed; the technique was driven from the formal supply chain - and, as later investigations found, into the informal one and across borders [J20]. The episode's full lesson took years to absorb: a banned process does not disappear when the demand for its look persists; it migrates to the workshops with no audits at all. The wash floor's lasers, which now deliver the same finishes without dust, are the real completion of the ban - the look was preserved, the silica retired [J40].

Chapter 38 - The worn-out garment

The last cost is what happens when the wearing is done. The average garment - across fashion, not only jeans - is now estimated to be worn as few as ten times before being discarded, and the system's aggregate is that the equivalent of a garbage truck of textiles is landfilled or incinerated every second, while less than one per cent of clothing material is recycled back into new clothing [J6]. Denim is paradoxically both the best and worst case. Best, because a jean's design life is long and its secondhand market is the strongest in apparel: old jeans are sold, swapped, handed down and collected like almost nothing else in the wardrobe. Worst, because the sheer unit volume - two billion new pairs a year against finite wearing capacity - guarantees a mountain of discards, and because the modern jean is engineered against its own recycling: elastane in stretch styles contaminates the cotton stream, and the garment's celebrated hardware - rivets, zips, buttons, leather patches, polyester thread - must all be removed before the cloth can re-enter a mill [J22].

The recycling technology itself splits two ways, both examined more closely in the next part. Mechanical recycling shreds the cloth back to fibre - which emerges shorter and weaker, fit for blending into new denim at modest percentages or for insulation and stuffing applications; denim's tolerance for shorter fibre, noted in Part III, makes it the friendliest destination for this stream, and recycled-cotton denims at ten to forty per cent recycled content are now ordinary mill offerings. Chemical recycling dissolves the cellulose back to a new fibre feedstock - the path taken by Sweden's Renewcell, whose Circulose pulp, made from discarded jeans and cottons, briefly stood as the emblem of circular fashion before the company filed for bankruptcy in February 2024 when financing and offtake failed to arrive at the needed scale; its assets and product were acquired and relaunched under the Circulose name [J24] [J25]. The bankruptcy mattered beyond one firm: it demonstrated that the bottleneck in clothing circularity is not chemistry but commitment - contracts, volumes and prices that make recycling a business rather than a promise.

The worn-out garment thus closes the loop the book opened with. A pair of jeans begins as water, fibre and dye; it spends years as biography; and it ends - at present, overwhelmingly - as waste, in a system that has not yet decided whether the end of a jean is a disposal problem or a raw material. The next part is about the people and rules trying to make it the latter.

The volumes at the end of the pipe deserve hard numbers, hedged as the data requires. Estimates of global textile waste run to tens of millions of tonnes a year, of which a small single-digit percentage returns as fibre; the United States alone sends millions of tonnes of clothing to landfill annually, and the export trade in used garments - the bales that feed Kantamanto and its sister markets - moves millions more across the world [J55] [J68]. Jeans, as the most numerous single category of durable casual garment, are a substantial slice of every one of those flows. The sorting infrastructure that a real recycling system would need - automated fibre identification, hardware removal, elastane handling - exists in pilots and showcases, not at the scale of the waste stream.

The garment's durability cuts both ways here, and the paradox is worth stating. A jean's long life is its environmental virtue: worn for years, its per-wear impact falls below almost any rival garment. But durability also means the waste stream arrives slowly and unevenly, starved of the steady, homogeneous feedstock that recycling economics crave - while the fast-fashion end of the market, which shortened the jean's life, feeds the stream with product too blended and too degraded to recycle well. The ideal circular jean - worn long, then recovered at quality - is precisely the one the market's two ends conspire not to produce [J22].

PART IX - THE REINVENTION

Chapter 39 - Colour without water

The vat is a water machine, so the first front in denim's reinvention is the dye application itself. The most striking industrial result so far came from an old name: in June 2019, Wrangler launched the first commercial collection of foam-dyed denim, under the Indigood programme - indigo applied to the yarn as a foam rather than a bath, eliminating, in the company's claim, one hundred per cent of the water conventionally used in the dyeing step, with large cuts in energy and chemical use alongside [J18]. Foam dyeing transfers a technique long used in carpet and fabric finishing to the indigo problem: if the dye liquor is carried in air-filled foam rather than a vat of water, the bath ratio collapses, the drying load shrinks, and the effluent largely disappears. Wrangler's then brand president framed the launch as an attempt to reset the sector's standards, and the technology - developed with Texas Tech researchers and the machinery maker Indigo Mill Designs - has since been offered to the industry rather than hoarded [J18].

Other routes attack the vat's chemistry rather than its volume. Pre-reduced indigo arrives at the mill already in leuco form, stripping the dyehouse's heaviest chemical handling - Stony Creek Colors' IndiGold is the natural-dye version [J28]. Electrochemical reduction replaces sodium dithionite with electrons, running the reduction on

current and leaving the bath far cleaner. Spray and digital application aim the dye only where the design wants it. Each of these has been demonstrated at scale; none has displaced the vat, because the vat is sunk capital, deeply understood, and tied to the exact ring-dyed character the product is made of. The pattern is the industry's general one: the improved process exists, and the obstacle is not invention but conversion - thousands of dye ranges in dozens of countries, each waiting for a commercial reason to change.

Where the reason has arrived, it has usually been a brand with enough volume to move a mill, and enough reputation at stake to want the story. That is the real significance of the Indigood launch: a mass-market American workwear brand, not a luxury label, put clean dyeing on the shelf at ordinary prices. If water-free dyeing can be sold at Wrangler's tier, the excuse for not adopting it anywhere else narrows to cost alone - and cost, in a regulated and water-stressed world, moves.

Foam dyeing's engineering is worth one paragraph of mechanism, because it shows what process innovation in this industry actually looks like. Instead of immersing the yarn sheet in vats of reduced indigo, the Indigood system - developed with the machinery maker and launched commercially with Wrangler in 2019 - carries the dye in a nitrogen-blanketed foam laid onto the yarn: the oxygen that would break the reduction is excluded, the water that carried the bath is largely eliminated, and the energy and effluent of the range fall with it [J21]. The product is indistinguishable in the garment - that is the point. The revolution, when it comes in this industry, arrives as a line item: same shade, less water, new machine.

Pre-reduced and liquid indigos attack the same vat from the chemistry side. The dye suppliers now ship indigo already reduced and stabilised - the mill adds no dithionite to prepare it - and the newest formulations remove the aniline contamination that has trailed synthetic indigo since 1897 [J28] [J29]. Each improvement is real, each is incremental, and the pattern of adoption is the one this book keeps finding: the top tier buys the cleaner process first, certification travels with the cloth, and the bottom of the market runs the old bath until the law or the buyer moves it. The vat is being reinvented one percentage point at a time.

Chapter 40 - Grown and brewed blue

The deeper reinvention is not how indigo is applied but how it is made, and here the industry is being pulled, a century and a quarter after BASF, back toward the field and forward into the fermenter at the same time.

The field first. Stony Creek Colors of Tennessee grows Indigofera on American farms as a cover crop - a legume that fixes nitrogen and suppresses nematodes while it grows - extracts the dye at its own facilities, and sells a plant indigo certified one hundred per cent biobased under the USDA's BioPreferred programme, verified by radiocarbon dating that distinguishes grown carbon from petrochemical carbon [J28] [J30]. The company's argument is chemical as well as agricultural: synthetic indigo is built from petrochemical precursors including aniline, and much of what is marketed as "natural" indigo is quietly adulterated with it; a certified plant source removes both the carbon and the carcinogen baggage from the dye bucket [J28]. Natural indigo has run on industrial rope ranges - Cone's 2017 natural-indigo selvedge line was the proof - at volumes still small but no longer symbolic [J30].

The fermenter is stranger and may matter more. Huue, a California biotechnology company, programs microbes to produce the indigo molecule by fermentation - the same logic by which insulin and most vitamins are now made - yielding a biosynthetic dye the company says carries five times less toxicity potential than the petrochemical product and drops into existing mill processes without new equipment [J29]. Nature covered the approach in 2021, and Berkeley's engineering school has tracked it since; the claims are a company's own, but the direction - colour grown in a tank rather than cracked from oil - is now a funded, staffed, shipping early-stage industry [J29].

Standing back: the dye that began in a leaf, moved to a plantation, and was conquered by the coal-tar flask is being asked to change its origin twice in one generation - back to the field on regenerative principles, and forward to biology as manufacturing. Either route, at scale, rewrites the first line of denim's environmental ledger. The race between them, and between both and the incumbent

petrochemical vat, will be decided by the oldest force in this book: cost per kilogram of consistent, fast, ring-dyeing blue.

The scale question hangs over every brewed-blue headline, and honesty about it belongs in this chapter. The demonstration garments exist; the pilot plants run; the brands have made their announcement capsules. What does not yet exist is production at the price and volume of the synthetic commodity - indigo is a bulk chemical with a bulk chemical's margins, and the bio processes must beat not only its footprint but its cost per kilogram at scales of thousands of tonnes [J27] [J28]. The honest status of grown and brewed blue in 2026: technically proven, commercially nascent, and dependent on exactly the willingness-to-pay and regulation that the rest of this Part describes.

The historical symmetry is too neat to pass without comment. Indigo has now been made four ways: from leaves by farmers, from coal tar by the first synthetic works, from petroleum by the modern chemical industry, and from sugar by engineered microbes. Each transition was fought on cost, quality and scale, and the incumbent lost every time the new route won on all three. The microbes have two of the three arguments still to make; the leaf, meanwhile, survives as the luxury - Stony Creek's American-grown indigo sells into the premium market precisely because it costs more and means more [J27] [J28]. The circle will close only when the newest route is also the cheapest.

Chapter 41 - The circular jean

If dyeing is the ledger's first line, disposal is its last, and here the industry's reinvention has a flagship: the Ellen MacArthur Foundation chose the jean, of all garments, as the subject of its circular-economy redesign programme. The Jeans Redesign, launched with guidelines in July 2019, was developed with eighty experts from brands, mills, manufacturers, collectors, recyclers and academia, and set a practical bar across four fronts: durability, material health, recyclability and traceability [J22] [J23]. The first redesigned jeans reached the market in June 2021; by 2023 more

than a hundred organisations in over twenty-five countries had produced jeans to the guidelines, and seventy-two per cent of participants reported overcoming the design challenges involved [J22]. The guidelines read like a checklist of everything this book has described going wrong: build to withstand repeated washing, source fibre that is safe and renewable or recycled, strip out the elastane and hardware that defeat recycling, and label the garment so its next life can find it [J23].

Choosing the jean for this exercise was strategic. It is the most standardised large-volume garment on earth; it already enjoys the strongest secondhand market in apparel; and its failure modes - blended stretch fabric, mixed-metal hardware, simulated wear - are the industry's in miniature. The project's own insight reports are candid about the gap between demonstration and system: participants proved a circular jean can be made; making the economy circular is a different and larger problem, requiring collection infrastructure, sorting, recycling capacity and - the Renewcell lesson - financing that survives contact with the market [J22] [J24].

The technical frontier underneath the programme is recycling quality. Mechanical recycling returns denim to fibre at the cost of length and strength, so recycled content has historically topped out at a minority blend; chemical and emerging biological routes promise cellulose recovered at near-virgin quality, at the cost of capital, energy and - so far - commercial fragility [J24] [J25]. Between the two sits the unglamorous work of design for disassembly: cotton thread instead of polyester, screws instead of blind rivets, no stretch where stretch is not needed. The circular jean turns out to be mostly a subtraction exercise - the removal, one by one, of the small decisions that made the garment unrecyclable in the name of comfort, cost or look.

The repair revival industrialised a virtue the jean had carried since the patch. Nudie Jeans, the Swedish brand, made free repairs for life a headline promise in 2012 and built repair shops into its stores, publishing repair counts as a marketing metric - tens of thousands of pairs a year returned to service by the company's own tailors [J66]. The economics are counterintuitive and sound: a repaired jean is a

retained customer, a data point on durability, and a story that sells the next pair at full price. Visible mending - sashiko-stitched patches, contrast darning - turned the repair into style, closing a loop with the hippie embellishment of Chapter 21 and the workwear patch of Chapter 2.

The resale-and-repair stack now reads as a single system: collect, grade, mend, resell. Levi's SecondHand sells repaired vintage [J65]; Nudie sells "Re-use" pairs alongside new [J66]; the platforms grade condition into price; and the whole apparatus revalues the garment's old property - that it improves with wear - into a modern service economy. The jean, uniquely among mass garments, had the durability to support an aftermarket; the aftermarket has now arrived, staffed and software-backed.

What the revival cannot yet do is set the industry's centre of gravity. Repairs and resale remain single-digit shares of the big makers' volumes, and the two-billion-pair new-garment engine [J33] runs on regardless. The revival's importance is directional: it demonstrates demand for longevity, builds the logistics of collection and grading that any future circular mandate will need, and keeps alive, in the market itself, the counter-model that Part IX will ask the rulebook to scale.

The business frontier is the harder climb. Circularity at scale requires the reverse logistics, sorting infrastructure and fibre-to-fibre capacity that Chapter 40 showed still bleeding cash; the resale and repair economies are growing but thin-margin; and the rulebook of Chapter 42 will push costs onto a volume model built on not paying them. The optimistic reading is that the technology curve and the regulatory curve are finally pointing the same way - cleaner process getting cheaper just as dirty process gets fined - and the jean, which has absorbed every other revolution in its history, will absorb this one too.

The pessimistic reading deserves its sentence: that the volume engine's economics are stronger than the reform wave, that Kantamanto's shadow [J68] and the hourglass's squeeze [J32] persist, and that the passport era documents the harm more precisely than it reduces it. This book has declined, throughout, to choose between its

machines and their shadows, and it declines here too. The jean's future will be written, as its past was, by the negotiation between what the cloth can be and what the market will pay for it to be - indigo on cotton, all the way down.

The Jeans Redesign results gave the circular idea its first hard test, and the results were instructive rather than triumphant. Brands, mills and factories covering a meaningful slice of the market committed to the guidelines - durable, traceable, recyclable, made with safe chemistry - and put compliant product into shops; the participants' reports then documented, with unusual candour, where the rules bit: elastane habits, hardware that would not unscrew, recycled fibre that would not run at speed, costs that would not vanish [J22] [J23]. The programme's real product was that documentation - a public record of exactly which screws resist the circle. Engineering roadmaps are made of such lists.

The mechanical recycling base underneath everything is older and duller than the pilots: the shoddy trade. For two centuries, old woollens and cottons have been shredded back to fibre - the trade centred on towns like Prato in Italy and Panipat in India - and respun into lower-grade yarn. Denim feeds it today: clipped, shredded, blended with virgin cotton, respun into the denim of the lower market, where a recycled-content percentage has become a selling line. The loop exists, in other words - it is just a loop that leaks quality and volume at every turn, serving the bottom of the market while the pilots aim at the top [J22] [J23].

Chapter 42 - The rulebook

Voluntary programmes move the willing; regulation moves everyone, and the regulation has now arrived. The European Union's Ecodesign for Sustainable Products Regulation - Regulation (EU) 2024/1781, in force since July 2024 - replaces the old energy-product ecodesign regime with a framework that can set durability, repairability, recycled-content and information requirements for almost any physical product, and its first working plan, for 2025 to 2030, names textiles and apparel among the priority product groups

[J26] [J27]. Attached to the framework is the Digital Product Passport: a data carrier on the product linking to its composition, origin, repair and recycling information. For apparel, the passport is being designed through the same delegated acts that will set the ecodesign requirements themselves [J26].

For denim specifically, the implications are concrete. Durability requirements will put a floor under fabric and construction quality in the world's largest single import market; recycled-content and recyclability rules will press directly on elastane blends and mixed trims; the passport will force the garment's supply chain - field, mill, laundry, factory - into disclosed, machine-readable form. An industry that has run on opacity will have to document itself. Compliance costs will fall hardest on the cheapest product and the smallest makers, which is the point: the regulation is designed to make the unmanaged edge of the trade - the Xintang workshops of the world - unable to sell into Europe without changing.

The same direction is visible beyond Europe in chemical rules, extended-producer-responsibility schemes for textiles, and import-market scrutiny of cotton's human-rights record. The arc is familiar from other industries: first the voluntary code (Levi's 1991 Terms of Engagement [J2]), then the campaign-driven collective standard (the Detox commitments), then the law. Denim's next decade will be shaped less by any fit or wash than by compliance - and the companies furthest ahead, as in every regulated transition, are the ones that began before they had to.

The European rulebook arrived in layers, and denim sits squarely in its path. The Ecodesign for Sustainable Products Regulation - Regulation (EU) 2024/1781, in force from July 2024 - extends ecodesign beyond energy products to nearly all physical goods, with textiles named an early priority; it empowers product rules on durability, recycled content, and substances, and it bans the destruction of unsold apparel for large companies from 2026 [J25]. The digital product passport, its companion instrument, will require a scannable record of a garment's composition, origin and compliance - the jean acquiring a document trail as standard equipment [J25]. Extended producer responsibility for textiles, adopted through the waste-framework revision, will make brands

pay into the collection and sorting of what they sell; the French scheme already runs, and the EU-wide version follows.

The United States moved more piecemeal - state-level chemistry rules, California's climate-disclosure statutes catching large apparel sellers, and a patchwork of marketing-claim enforcement - while the claims regimes tightened everywhere: greenwashing directives in Europe, securities-disclosure exposure for sustainability statements, and consumer-protection actions against vague "eco" labels. The direction is uniform across jurisdictions: the environmental and social language of Part VIII is graduating from marketing copy to legal statement, auditable and punishable.

For the jean the rulebook lands on specific anatomy. The passport will name its fibre, its mill, its dye; the destruction ban touches the volume tier's overproduction; EPR fees will price its end-of-life; durability rules will test its seams. A garment that has been the same object for 170 years is about to carry a dossier. The industry that once answered to no inspector now answers to many - and the change, more than any innovation in this book, is what makes the next decade's denim a different industry from the last one's.

The product passport deserves its own explanation, because it will change the physical garment's relationship with information. Under the Ecodesign framework, a regulated product will carry a data carrier - a QR code or similar - resolving to a structured record: composition, origin of materials, manufacturing chain, environmental performance, repair and recycling instructions [J25]. For jeans the record will run through every tier of this book: farm, gin, spinner, dyer, weaver, factory, laundry. The industry's supply chains, which brands themselves mapped only partially for a century, will become legible to a customs officer, a recycler, a journalist or a shopper with a phone. Whatever one thinks of the compliance burden, the era of the anonymous jean is ending.

The claims crackdown runs parallel and may bite sooner. European rules on environmental claims now require that words like "sustainable", "conscious" and "eco" be substantiated, specific and verifiable, and enforcement and litigation have already reached major apparel sellers; securities regulators, meanwhile, treat

published sustainability figures as disclosures with liability attached. The practical effect on denim marketing is visible in any current catalogue: percentages instead of adjectives, certifications instead of slogans, and lawyers reading the copy where only copywriters used to. The green age of denim marketing is ending; the documented age is beginning [J25].

Chapter 43 - The second life

The cheapest sustainable jean is the one already made, and the market for already-made jeans is booming into an industry of its own. Vintage Levi's have been collectable for half a century - Japanese buyers built the trade in the 1980s, scouring American rag-houses for old 501s - but what was a connoisseur's market has generalised. Online resale platforms turned secondhand clothing into a mainstream channel growing several times faster than the primary market; brands that once feared cannibalisation now run their own take-back and recommerce programmes; and at the apex, archival denim - deadstock and worn examples of significant jeans - trades as a documented collectible, with the wear patterns that Part I described functioning as provenance.

Repair is the quieter half of the second life. Denim's construction rewards it: the cloth darns and patches handsomely, and a repaired jean reads as more itself rather than damaged. The visible-mending movement made the virtue aesthetic - sashiko-style stitching in contrast thread, patches worn as badges - and several brands built loyalty programmes on free lifetime repairs. The raw-denim community had, as usual, been there first: its whole discipline of wearing one pair for years is a repair culture wearing a hobby's clothes.

The second life matters to the industry's future arithmetic. Every durable jean kept in circulation displaces some fraction of a new one, and the displacement is precisely what the circular-economy rulebook of the previous chapter is built to reward - the Jeans Redesign's first principle is "used more," before any question of recycling [J22]. The open question is whether second life can be

more than a complement to two billion new pairs a year. Resale currently redistributes demand; it does not yet visibly reduce production. The garment that lasts fifteen years has been invented; the business model that thrives on making fewer of them has not. That gap - between the product's durability and the industry's volume - is the truest measure of how far the reinvention has to go.

The secondhand market industrialised what the vintage shops began. ThredUp, Depop, Vinted, Grailed and their peers built resale platforms with logistics, photography and pricing engines; the platforms' growth rates outran new apparel for years, and jeans - durable, size-tagged, endlessly re-sellable - are among their most liquid categories [J55]. The effect on the industry's structure is subtle but real: a garment that retains resale value changes its own first-sale economics, and the brands noticed. A jean that will sell again at forty dollars is a different product proposition from one that dies at the bin, and marketing learned to say so.

The brands' own re-entry followed. Levi's SecondHand, launched in 2020, buys back worn Levi's, cleans and grades them, and resells them under the company's own name - the original maker entering its own aftermarket, with buy-back credit feeding new sales [J65]. The programme is small against the volume business, but its symbolism is large: the company that defined the new jean now certifies the used one, monetising the durability it always advertised. Others followed with trade-in and resale pilots, and the used jean acquired something it never had before - a supply chain, with collection, grading, refurbishment and retail of its own.

Kantamanto is where the ledger of reuse meets the ledger of waste, and the meeting is uncomfortable. Accra's great market receives the Global North's castoffs by the container - millions of garments a week - and sustains tens of thousands of traders who sort, mend, upcycle and sell; it is one of the world's largest reuse economies and a genuine engine of livelihood [J68]. It is also a terminus: studies find a large share of each bale unsellable on arrival, passing to dumps and beaches, so that the market functions partly as the rich world's waste export with a market attached [J68]. Both descriptions are accurate. The second life of jeans is a real economy with a real

shadow, and policy that treats it as either pure solution or pure dumping will misgovern both.

The grading trade inside the second life is a craft economy of its own. A bale of used jeans arriving at a sorting warehouse is triaged in minutes per piece: sellable as-is, worth mending, fit only for the rag grade - and the grades set prices that flow back up the chain to the collectors and forward to the market stalls. Kantamanto's traders add their own transformations on top: washing, repairing, re-cutting, overdyeing, turning unsellable widths into shorts and skirts and bags. The market's reputation as dumping ground and its reality as an engine of livelihoods are the same fact photographed from two angles; the studies that count the unsellable share of each bale and the studies that count the incomes are both measuring the same river [J68].

The brands' resale experiments are best read as options on a possible future rather than businesses of the present. Levi's SecondHand buys back and re-sells the company's own used product; Nudie's repairs and re-use shelves do the same at boutique scale [J65] [J66]. The volumes are small, the logistics are real, and the strategic logic is clear: if regulation, taxation or taste ever tilts the market toward the used garment, the companies that already know how to collect, grade, mend and resell will own the transition. The second life is today a few percent of the business and one hundred percent of its insurance policy.

PART X - THE MEANING

Chapter 44 - How many jeans

Dependence on a material can be measured, and denim's numbers are of a kind few materials achieve. The market research summarised in Part VII puts annual production above two billion pairs [J33] [J34]. Ownership surveys in the garment's home market find the average American holding about seven pairs, and re-buying at a steady rate [J8]. Simple multiplication says the world's wardrobes contain on the order of ten billion pairs of jeans at any time - more than one for every human alive, concentrated in the wardrobes of the relatively rich third of humanity that buys clothing as more than necessity.

The wearing is as remarkable as the owning. Jeans are worn by farmers and presidents, schoolchildren and surgeons on their days off, models and mechanics, in every climate and on every continent; they are the one garment acceptable in both a Shanghai boardroom on casual Friday and a Rajasthani wheat field. No national dress, no religious vestment, no uniform has ever achieved comparable penetration. The jean is the closest thing humanity has produced to a universal garment, and it reached that status without any authority decreeing it - by being cheap, tough, comfortable, washable, and silently expressive of a cluster of ideas (informality, youth, America, work, authenticity) that much of the world decided it wanted to say.

That is the true answer to the question this library asks of every item: how much do humans depend on it? Not at all, in the way we depend on penicillin or the shipping container - civilisation would not halt without denim. Totally, in the way of habit and identity - a garment woven this deeply into daily life, self-presentation and global employment does not get discarded; it gets reformed. The industry's future fights, chronicled in Part IX, are over the terms of that reform.

What the jean will be asked to do next can be read from the pressures already on it. The rulebook will require it to arrive with a dossier: fibre origin, chemistry, footprint, repairability - a garment with paperwork [J25]. The circular programmes will require it to be collectible: designed for disassembly, tagged for sorting, worth recovering [J22]. The resale market will require it to hold value: durability as an asset feature rather than a nostalgic virtue [J65]. And the consumer of the next decades - raised on the climate ledger - will require it to account for itself in a vocabulary of litres, grams and years that the 501's inventors never imagined their product would speak.

The industry's structure will be rewritten by the same forces. The hourglass mill layer will consolidate further around documented capability; the factory belts will sort between those that can carry compliance costs and those that will fight for the unaudited remnant of the market; and the brands will divide between those selling certified virtue at a premium and those selling unexamined volume at the floor. The jean will exist at both poles, as it always has, but the middle - the undifferentiated branded middle - is the tier the squeeze empties.

The ownership numbers, where they can be got, are of the same order everywhere. Wardrobe surveys in the rich countries find jeans in nearly every closet, typically several pairs; the American figures commonly cited run to half a dozen pairs or more per person, worn weekly or oftener [J33]. But the more telling evidence is the wear pattern: jeans are not owned-and-occasioned like a suit or a dress but lived in, and a pair in active service accumulates wear-hours that few garments in the wardrobe match. The industry's two billion pairs a year are not being warehoused; they are being worn out - the market's volume is usage, not hoarding.

There is no comparable garment. T-shirts approach the numbers but not the durability; suits have the durability but not the numbers; sneakers have both but not the century. The jean's combination - universal across age, sex, class and nation, identical in essentials across all of them, and improving with the wearing - has no rival in the history of dress. When this library asks of a material thing "how much does the world depend on it?", the jean answers with a peculiarity: the dependence is so complete that it has become invisible, which is the final form a successful material takes [J33] [J34].

Chapter 45 - What the fades record

It is right to end where the object itself ends: as a record. A worn pair of jeans is a diary written in dye. The whiskers at the hip are the body's hinge, drawn in pale lines; the honeycombs behind the knees are every stair climbed and every chair sat in; the faded rectangle on the back pocket is a wallet or a phone, dated as precisely as a tree ring by its shape; the blown-out crotch is the miles; the pale hem is the years. Two people can buy the same pair on the same day and in five years own two garments with nothing in common but the label. No other mass-produced object so faithfully accumulates its owner's biography, because no other was engineered - accidentally, as Part II showed - with a dye system that erases itself in exact proportion to use.

The material thinker, looking at a glass and seeing the furnace and the pipeline, can look at a faded jean and see the whole of this book in one leg: the cotton field in the cloth's weight, the vat in its blue, Baeyer's flask and BASF's gamble in the dye's cheapness, Davis's rivet at the pocket corner, the shuttle or the air-jet in the edge, the wash floor in the too-perfect whiskers of the shop-bought pair, the Soviet black market and the Osaka auction house in what the garment still means. Philosophy, this library's patron says, begins with material thinking. Denim jeans may be its friendliest subject: an item where the material, the history, the industry and the meaning are all legible in a single object that half the readers of this book are probably wearing.

The story has no final chapter, which is the last thing to say about it. A garment patented in 1873 as a fix for ripping seams is now a frontier of fermentation chemistry, product passports and circular design, and its next hundred years will be argued in the same three currencies as its first: what it costs to make, what it means to wear, and who pays for the difference. The cloth of Nimes has always found a way to be the uniform of whatever comes next.

The deep continuity runs under every discontinuity this book has recorded. The cloth is still indigo-dyed cotton twill, as it was in Nimes and Genoa; the garment is still five pockets, rivets, a fly, as Davis and Strauss settled it; the factories still run on human hands guiding fabric under needles, as they have since the 1870s [J33]. The revolutions have been real - synthetic dye, stretch fibre, laser finishing, the passport - and each one was absorbed into an object that remained recognisable across them all. The jean's history is the history of a design so fit to its purposes that it can host any technology and any meaning without becoming something else.

That is the final answer to the book's opening question. The jean conquered the world not because it was marketed well, though it was; not because it was cheap, though it is; not because it signified rebellion or America or ease, though it signified all of them in turn. It conquered because it was, first and last, a superb piece of equipment - durable beyond need, repairable, improving with use, honest about its age - and because every meaning layered onto it afterwards could be worn on a chassis that worked. The meanings are why people wanted it. The cloth is why they kept it. Any account of the next century of denim should be read against that order: the symbolism is the weather; the twill is the ground.

Two commitments govern what this book has said, and they bear restating at the end. The first is evidentiary: every factual claim carries a tag to the companion volume, where the source is named, the claims it supports are listed, and the reading status - full, excerpt, or located record - is stated honestly. Forecasts are labelled as forecasts. Where the record is thin, as it is for the company's pre-1906 decades, the book has said so rather than filling the silence with plausible invention. The second commitment is structural: the book has refused to choose between the garment's two truths - the

superb object and the costly system - because the industry itself has never chosen between them, and an account that picks one is an advertisement or an indictment, not a history.

The jean ends the book as it began it: blue, twilled, riveted, everywhere. Somewhere in the time it took to read these chapters, the world's factories finished tens of thousands more pairs, its rivers took their share of the dye houses' output, its markets moved their containers of the discarded, and its wearers wore in a few more days of personal fade. The machinery and the meaning run on together, as they have for 170 years. The story of denim jeans is not finished; it is, like the cloth itself, still in the dye.

The forensic detail of a worn jean rewards the attention this book has been training. Whiskers radiate from the crotch seam where the cloth flexes at every step; honeycombs stack behind the knee in the order the wearer bends; the right rear pocket carries the wallet's rectangle, the front pockets the phone's outline and the keys' constellation; the hem's roping records how the owner cuffs and walks; the seat and thighs fade in the map of the body itself. Two pairs of the same model, sold the same day, are different objects in a year - each a slow self-portrait in indigo. No other mass product writes its owner's biography into its own surface as a matter of ordinary use.

That property explains the garment's strange afterlife as an emotional object. People keep worn-out jeans past all utility; the vintage market pays premiums for other people's wear; the archives of the brands collect the garments of dead workmen like documents [J69]. The jean acquired, without any engineer intending it, the properties of a diary. It is the final answer to the question of why this cloth, of all cloths: denim is the material that remembers, and a civilisation that produces everything else in disposable uniformity has kept one object that insists on recording its life.

Chapter 46 - A denim glossary

Terms used in this book and in the trade.

Arcuate - The curved double stitching on jeans' back pockets; Levi Strauss's version, two crossing arcs, is among the oldest trademarks in continuous use.

Bartack - A dense zigzag stitch reinforcing a stress point - belt loops, pocket corners, fly bases.

Broken twill - A twill weave whose diagonal reverses at intervals, cancelling the fabric's tendency to twist in the leg.

Chainstitch roping - The puckered, ridged wear pattern at a chainstitched hem, prized in vintage and reproduction jeans.

Cinch-back - A buckle and strap at the rear waistband of early jeans, used to adjust the waist before belts became standard.

Dungaree - A coarse cotton work cloth named for Dongri, near Bombay; in American usage, bib overalls; in older British usage, workwear generally.

Fustian - A family of heavy, hard-wearing cloths with a linen warp and cotton weft; the Genoese ancestor of jean fabric.

Honeycombs - The grid of pale crease lines worn into the cloth behind the knees.

Indigotin - The blue pigment molecule of indigo, C16H10N2O2, whether extracted from plants, synthesised from petrochemicals, or brewed by microbes.

Leuco-indigo - The reduced, soluble, yellow-green form of indigo in which the dye enters the fibre; it oxidises in air back to blue pigment.

Loomstate - Cloth as it leaves the loom: unsinged, unsanforized, unwashed, and not yet shrunk.

Open-end (rotor) spinning - A fast spinning method producing bulkier, cheaper yarn of lower strength than ring spinning.

Ounce weight - Denim's standard measure: ounces per square yard. Jeans cloth commonly runs from about five to sixteen ounces, with heavier for specialist and reproduction markets.

Raw denim - Denim sold unwashed after weaving, dark and stiff, intended to be faded by the wearer rather than the laundry.

Ring dyeing - The shallow indigo dyeing of yarn in successive dips, leaving the core white; the mechanism behind denim's fading.

Ring spinning - The traditional spinning method producing strong, fine, slightly irregular yarn; specified by the premium and heritage markets.

Rivet - The metal stud headed through seam layers at stress points; the device at the heart of the 1873 Davis-Strauss patent.

Rope dyeing - Indigo dyeing of warp yarn in loose ropes, giving controlled penetration and stretch; the premium method.

Sanforized - Cloth treated by compressive shrinkage so that it will not shrink meaningfully in washing; Sanford Cluett's patented process, licensed worldwide from the 1930s.

Selvedge - The self-finished edge of shuttle-woven cloth; its coloured ID thread signals the loom type and mill.

Slasher dyeing - Indigo dyeing of warp yarn laid out as a flat sheet; the high-throughput method.

Slub - Deliberate thick-and-thin variation in yarn, once a defect, now engineered for vintage texture.

Stonewashing - Abrading garments with pumice in industrial washers to fade and soften them; largely displaced by enzymes and lasers.

Twill - A weave whose crossings step sideways row by row, forming a diagonal rib; denim is a three-by-one, warp-faced twill.

Waist overalls - The trade name under which riveted jeans were sold into the early twentieth century, distinguishing them from bib overalls.

Warp and weft - The lengthwise threads held on the loom (warp) and the crosswise threads woven through them (weft). In denim the warp is indigo, the weft undyed.

Whiskers - The faded crease lines radiating from the crotch and hips, worn in by the body's hinge or simulated by the laundry.

Yoke - The V-shaped panel at the back of a jean below the waistband, shaping the seat.

Atari - The Japanese term for a jean's pattern of fades and wear marks, from the word for a winning strike; the studied opposite of factory distressing.

Crocking - The rubbing of dye off a fabric's surface onto other materials; indigo's poor rub-fastness is why new jeans blue the furniture and the wearer's legs.

Greige - Cloth in its unfinished state straight from the loom, before singeing, shrinking or any wet processing; pronounced "gray".

Jacron - The paper-and-plastic material of many back-patch labels, used where leather is unwanted; named for the original product.

Kasuri - Japanese ikat weaving, in which threads are dyed before weaving to make patterned cloth; the indigo craft tradition from which mills like Kaihara grew.

Nep - Small tangled knots of fibre in yarn or cloth; a defect in ordinary fabric, cultivated as texture in some denims.

Overdye - A second dye applied over finished cloth or garments, tinting the indigo toward black, grey or colour; the quick route to a new "wash" without a new cloth.

Pumice - Porous volcanic glass, the original stonewashing stone; floated on water, broke down in the drum, and wore both the garment and the machine.

Vat dye - The class of dyes, indigo among them, applied from a chemically reduced, soluble state and fixed by oxidation inside the fibre.