

# The Archaeometallurgy of Blacksmithing Charcoal: Historical Production Methods and the Operation of Traditional Earthen Clamps

The manipulation of ferrous metals through localized thermal application represents one of the foundational pillars of human technological advancement. For millennia, before the widespread industrial adoption of mineral coal and purified metallurgical coke, wood charcoal served as the exclusive solid fuel capable of achieving the extreme temperatures required for smelting iron ore and forge-welding steel<sup>1</sup>. The codification of these early pyrotechnological methods was extensively documented in historical treatises, most notably Georgius Agricola's 1556 masterwork *De Re Metallica* and Henri-Louis Duhamel du Monceau's 1761 *Art du Charbonnier*, which provided early empirical analyses of smelting furnaces, forced-air bellows, and woodland charcoal production techniques<sup>1</sup>.

The production of high-quality blacksmithing charcoal transcends the mere incineration of wood; it is a highly calibrated exercise in applied physical chemistry, thermodynamics, and silviculture. The transformation of raw lignocellulosic biomass into a matrix of nearly pure elemental carbon requires a controlled environment where destructive distillation—or pyrolysis—can occur without the complete oxidation of the fuel<sup>6</sup>. The resulting material possesses a dramatically elevated fixed carbon content and energy density, enabling the blacksmith to generate a concentrated, neutral-to-reducing atmosphere necessary to heat steel to its plastic state without inducing catastrophic oxidation<sup>1</sup>.

This exhaustive analysis explores the historical, chemical, and practical dimensions of blacksmithing charcoal. The report investigates the thermodynamics of wood pyrolysis, the historical forest management systems developed to sustain metallurgical fuel supplies, and the fluid dynamics distinguishing charcoal forges from mineral coal hearths. Furthermore, it provides a comprehensive, sequential methodological guide to constructing, operating, and harvesting a traditional earthen charcoal clamp (or mound kiln) for application in contemporary hobbyist metallurgy, culminating in the integration of this fuel into a historically accurate side-blast dirt forge.

## The Biochemical and Thermodynamic Mechanics of Pyrolysis

Raw wood is fundamentally unsuitable for high-temperature metallurgical applications. Typical air-dried wood possesses substantial inherent moisture alongside complex biopolymers, including cellulose, hemicellulose, and lignin<sup>10</sup>. When raw wood is combusted in an open, oxygen-rich environment, a significant portion of its total potential thermal energy is immediately consumed by the latent heat of vaporization required to drive off the cellular moisture<sup>12</sup>.

Furthermore, the rapid combustion of volatile organic compounds produces copious amounts of smoke and long, relatively cool flames that fail to concentrate thermal energy into the tight focal point required for heating a steel workpiece<sup>12</sup>.

Charcoal production mitigates these inefficiencies through pyrolysis—a thermochemical decomposition process occurring at elevated temperatures in an oxygen-starved environment<sup>10</sup>. The process breaks down the large macromolecules of the wood, driving off the moisture and volatile compounds, thereby concentrating the carbon matrix into a lightweight, highly porous structure<sup>2</sup>.

The pyrolysis of woody biomass is a sequential progression of endothermic and exothermic reactions that correlate directly with the decomposition temperatures of the primary structural biopolymers. In the initial stage, as the temperature of the biomass is raised from ambient to approximately  $200^{\circ}\text{C}$ , the application of external heat drives off free and chemically bound moisture<sup>10</sup>. This pre-pyrolysis phase is strictly endothermic, requiring constant thermal input to overcome the heat capacity of the water<sup>10</sup>. As the temperature approaches  $220^{\circ}\text{C}$ , the wood begins to undergo preliminary physical breakdown, releasing water vapor, trace carbon dioxide ( $\text{CO}_2$ ), and minor amounts of carbon monoxide ( $\text{CO}$ )<sup>10</sup>.

As the internal temperature escalates into the  $200^{\circ}\text{C}$  to  $315^{\circ}\text{C}$  range, hemicellulose—the least thermally stable of the wood polymers—begins to decompose rapidly<sup>10</sup>. This degradation yields predominantly volatile products, non-condensable gases, and significant quantities of acetic acid<sup>10</sup>. It is within this precise thermal window, typically calculated to cross a threshold near  $280^{\circ}\text{C}$ , that the overall thermodynamic reaction transitions from an endothermic to an exothermic state<sup>18</sup>. Differential scanning calorimetry (DSC) studies of biomass pyrolysis confirm that the formation of the solid carbonaceous char matrix is highly exothermic, eventually releasing enough internal thermal energy to sustain the continued decomposition of the surrounding wood without requiring further external heat input<sup>11</sup>.

Following the breakdown of hemicellulose, cellulose decomposition accelerates between  $315^{\circ}\text{C}$  and  $400^{\circ}\text{C}$ <sup>10</sup>. The primary products of this phase include condensable vapors, specifically levoglucosan, which further crack into lighter gases and bio-oils upon exposure to the escalating heat<sup>10</sup>. Finally, lignin, a highly complex and robust aromatic polymer, degrades over a much broader temperature spectrum ranging from  $160^{\circ}\text{C}$  to  $900^{\circ}\text{C}$ , though the bulk of its decomposition occurs between  $200^{\circ}\text{C}$  and  $500^{\circ}\text{C}$ <sup>10</sup>. The degradation of lignin is primarily responsible for the physical structural integrity of the resulting charcoal, yielding a high percentage of the final fixed carbon mass<sup>10</sup>.

The precise thermal balance of pyrolysis remains a subject of complex thermodynamic modeling, as the endothermic volatilization of liquids continuously competes with the highly exothermic formation of the char matrix<sup>19</sup>. However, for the practical charcoal burner, the onset

of the exothermic reaction is the critical threshold. Recognizing when the wood begins to actively sustain its own decomposition dictates the transition from actively firing the kiln to restricting oxygen and managing the burn rate<sup>19</sup>.

## **The Chemical By-products of Carbonization**

The destructive distillation of wood produces three primary fractions: the solid carbon residue (charcoal), non-condensable combustible gases (syngas), and a complex liquid condensate<sup>7</sup>. In industrial settings, the recovery of these secondary fractions dictates the economic viability of the operation.

The liquid fraction separates gravitationally into heavy wood tar and an aqueous phase historically known as pyroligneous acid or wood vinegar<sup>7</sup>. Pyroligneous acid is a highly complex chemical mixture containing over two hundred distinct compounds. Its primary constituents include methanol (historically referred to as wood spirit), acetone, acetic acid, and numerous phenolic compounds such as guaiacol, 4-methylguaiacol, and syringol<sup>16</sup>. These specific phenols are responsible for the characteristic aroma and flavor profile of wood smoke, explaining the historical crossover between charcoal production and the preservation of smoked foods<sup>25</sup>.

In addition to these compounds, the pyrolysis process generates polycyclic aromatic hydrocarbons (PAHs), which are formed during the incomplete combustion and thermal cracking of the organic matter<sup>25</sup>. Historically, large-scale industrial retorts were designed to capture, distill, and refine these by-products for commercial use in the textile, solvent, and chemical industries<sup>7</sup>. However, in the traditional earthen mound kilns utilized by pre-industrial colliers and modern hobbyists, these tars and acids either condense on the cooler outer layers of the earthen mound, seep into the substrate, or are expelled into the atmosphere as thick, acrid smoke<sup>29</sup>.

## **Silvicultural Foundations of Historical Charcoal Production**

The metallurgical demands of the pre-industrial world placed immense and unprecedented pressure on local forest ecosystems. A single blast furnace, bloomery, or large-scale forging operation could consume thousands of bushels of charcoal annually<sup>31</sup>. Because the conversion efficiency of traditional charcoal mounds rarely exceeded a 25% to 30% gravimetric yield, the continuous harvesting of massive tracts of woodland was required to sustain even modest iron production<sup>33</sup>.

To prevent total deforestation and ensure a sustainable, localized supply of fuel, European societies developed highly regulated silvicultural systems. The logistical constraints of pre-industrial transport meant that it was far more economically viable to convert the wood into lightweight, high-energy charcoal deep within the forest and transport the finished fuel, rather than hauling massive volumes of heavy, moisture-laden raw timber to the centralized forges<sup>36</sup>.

### **The Coppice-with-Standards System**

The most prominent forest management architecture developed to meet this demand was the "coppice-with-standards" system<sup>37</sup>. Coppicing exploits the biological capacity of most broadleaved hardwood species to regenerate vegetatively after being severed near ground

level<sup>38</sup>. The remaining stump, known as the "stool," rapidly produces a dense cluster of new shoots fed by the established and mature root system<sup>40</sup>. Because the root system possesses massive energy reserves, coppice shoots grow at an accelerated rate compared to trees grown from seed, allowing for a rapid, sustainable harvest cycle<sup>37</sup>.

The coppice-with-standards architecture was specifically optimized to supply both the metallurgical and construction industries simultaneously without degrading the ecological stability of the woodland<sup>37</sup>. The forest was divided into designated parcels, frequently referred to as cants or coupes<sup>37</sup>. The underwood—comprising species like hazel, hornbeam, and field maple—was harvested on a short rotation cycle of approximately 15 to 30 years<sup>37</sup>. This rotation schedule provided raw material with an ideal diameter (typically 3 to 6 inches) for efficient carbonization in a charcoal clamp, requiring minimal splitting by the collier<sup>37</sup>.

Scattered purposefully throughout the coppice underwood were individual "standards," typically long-lived, robust species such as pedunculate oak (*Quercus robur*) or sessile oak (*Quercus petraea*)<sup>37</sup>. These trees were strictly exempted from the short coppice rotation. Instead, they were allowed to mature over an extended 100-year to 120-year cycle to provide massive structural timber for shipbuilding, architecture, and engineering projects<sup>37</sup>. The standards were meticulously spaced to ensure they cast only a light canopy shade, allowing sufficient solar radiation to reach the regenerating coppice stools below<sup>37</sup>.

### The "Holznot" and Wood Selection Criteria

Despite the implementation of sustainable coppicing practices, the exponential growth of the iron, glass, and leather industries in the 17th and 18th centuries induced widespread socioeconomic fears of a *Holznot* (wood shortage) across Central Europe<sup>43</sup>. While modern historical ecology suggests that the narrative of total deforestation was frequently exaggerated by contemporary governments to justify centralized control over woodland resources, the perceived scarcity of timber accelerated the transition toward mineral coal in regions where subterranean seams were accessible, fundamentally altering the trajectory of industrial metallurgy<sup>14</sup>.

For the blacksmith, the species of wood utilized for the production of charcoal dictates the ultimate performance of the fuel in the forge. Not all charcoal is created equal; its physical properties, energy density, and structural durability are directly inherited from the cellular architecture and density of the parent wood<sup>47</sup>.

| Wood Classification    | Common Species                                                              | Charcoal Characteristics                                              | Suitability for Metallurgical Forging                                          |
|------------------------|-----------------------------------------------------------------------------|-----------------------------------------------------------------------|--------------------------------------------------------------------------------|
| High-Density Hardwoods | Oak ( <i>Quercus spp.</i> ), Beech ( <i>Fagus sylvatica</i> ), Hickory, Ash | Extremely high density, prolonged burn time, high fixed carbon yield. | <b>Excellent.</b> Provides maximum thermal output, structural stability in the |

|                                 |                   |                                                                                                                              |                                                                                                                                                      |
|---------------------------------|-------------------|------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                 |                   | Resists mechanical crushing from blast pressure <sup>47</sup> .                                                              | firepot, and a long working time per fuel charge <sup>9</sup> .                                                                                      |
| <b>Medium-Density Hardwoods</b> | Birch, Elm, Maple | Medium burn time, moderate density, reliable heat output. Slightly lower volumetric energy density than oak <sup>49</sup> .  | <b>Good.</b> Highly suitable for general blacksmithing, shaping, and light heat treating <sup>49</sup> .                                             |
| <b>Softwoods / Conifers</b>     | Pine, Spruce, Fir | Low density, rapid burn rate, excessive spark generation, highly friable. Lower fixed carbon ratio by volume <sup>49</sup> . | <b>Poor.</b> Wastes fuel rapidly, requires constant replenishment, fails to support the fuel dome, and presents a severe fire hazard <sup>49</sup> . |

The cellular density of hardwoods translates directly into a higher gravimetric energy yield and superior compressive strength. Hardwood charcoal resists crumbling under the weight of heavy steel workpieces and the pneumatic pressure of the bellows<sup>47</sup>. This structural integrity is paramount, as it maintains the crucial interstitial air gaps required for uniform oxygen distribution and efficient combustion<sup>49</sup>. Softwood charcoal, while capable of reaching high temperatures, consumes itself so rapidly that the blacksmith is forced to spend an inordinate amount of time managing and feeding the fire rather than physically shaping the metal<sup>49</sup>.

## The Earthen Charcoal Clamp: A Methodological Guide

The historical transition of raw timber into high-grade metallurgical charcoal has evolved through several distinct technological phases, carefully balancing capital expenditure, labor requirements, and thermodynamic efficiency. While modern industrial production relies on continuous-feed steel retorts that capture off-gases to achieve high mass yields, the pre-industrial world relied almost exclusively on the earthen clamp, known in Germanic traditions as the *Meiler* or *Kohlemeiler*<sup>22</sup>.

Built entirely above ground, the earthen clamp involves stacking wood in a precise geometric hemisphere and sealing it with an impermeable layer of organic matter and earth<sup>29</sup>. This architecture allows the charcoal burner (the collier) strict control over the intake of oxygen via adjustable draft holes<sup>29</sup>. The construction and operation of a clamp is a delicate exercise in managing restricted combustion; the objective is to harness the exothermic energy of a

localized fire to heat the entire mass to the carbonization threshold ( $> 400^{\circ}\text{C}$ ) while simultaneously restricting oxygen ingress to prevent the bulk of the wood from incinerating into

useless white ash<sup>29</sup>.

Safety Note: The pyrolysis of wood generates lethal concentrations of carbon monoxide (CO), a colorless, odorless, and highly toxic gas. The Occupational Safety and Health Administration (OSHA) Permissible Exposure Limit (PEL) for CO is 50 parts per million (ppm) over an 8-hour time-weighted average, while the National Institute for Occupational Safety and Health (NIOSH) imposes a Recommended Exposure Limit (REL) of 35 ppm<sup>8</sup>. Exposure to concentrations approaching 400 ppm can incapacitate or kill within an hour<sup>8</sup>. The construction and operation of a charcoal clamp must occur exclusively outdoors, in an open area with excellent cross-ventilation, completely isolated from enclosed spaces, garages, or dwellings<sup>8</sup>.

## **Site Preparation and Soil Micromorphology**

The foundation of a successful clamp dictates the thermodynamic efficiency of the entire burn. The selected site must be flat, highly compacted, and well-drained<sup>15</sup>. A poorly drained site will wick subterranean moisture upward into the burning wood, arresting the pyrolysis reaction, creating cold spots, and resulting in large pockets of uncarbonized wood<sup>15</sup>.

The site must be cleared of all loose organic material, dry grass, and surface stones down to bare mineral soil to prevent the fire from escaping the perimeter of the mound<sup>15</sup>. Furthermore, the location should ideally be shielded from prevailing winds, as strong, unpredictable gusts can drive uncontrolled oxygen into the draft holes of the mound, causing localized incineration and devastating the charcoal yield<sup>31</sup>.

Historically, colliers heavily preferred to build new clamps over the exact footprint of previous burns<sup>5</sup>. The soil in these recurring hearth areas is already sterilized, deeply calcined by previous exposure to extreme heat, and heavily impregnated with residual charcoal dust and ash<sup>5</sup>. This repeated utilization alters the local soil micromorphology, leading to distinct podzolization and the creation of a highly insulative, dry base that reflects thermal energy back up into the active mound rather than allowing it to dissipate into the earth<sup>5</sup>.

## **Fuel Harvesting, Sizing, and Stacking**

To ensure the wood carbonizes uniformly, the raw material must be sized with strict consistency. Mixing massive, thick logs with thin branches will result in the smaller material incinerating into ash long before the thick logs have completed their endothermic dehydration phase<sup>57</sup>. The wood should ideally be seasoned for several months; processing "green" wood with high moisture content drastically reduces the final charcoal yield, as the internal exothermic heat of the clamp is wasted vaporizing the cellular water rather than driving the pyrolysis front<sup>13</sup>.

The logs are typically cut to uniform lengths of 3 to 4 feet<sup>22</sup>. Timber exceeding 4 inches in diameter should be mechanically split to expose the inner grain, thereby accelerating the egress of internal moisture and volatile gases during the burn<sup>31</sup>.

The architectural erection of the timber mound begins with the establishment of the central chimney, historically referred to as the *Quandel* or "fagan"<sup>29</sup>. A long, straight, green wooden pole is driven deep into the absolute center of the cleared site<sup>29</sup>. Alternatively, three or four straight, split logs are arranged vertically to form a hollow, triangular, or square central chimney<sup>22</sup>. This void must extend from the soil base to the absolute top of the projected mound<sup>32</sup>.

The collier then constructs the "foot" or inner tier of the mound by stacking the split hardwood tightly against the central chimney<sup>32</sup>. The logs must be stood vertically on end, leaning slightly inward toward the center to create a highly stable, conical shape<sup>15</sup>. The tighter the wood is packed together, the fewer interstitial air pockets will remain, drastically reducing the risk of uncontrolled internal combustion and ensuring a higher density of finished charcoal<sup>15</sup>.

The construction radiates outward, building concentric rings of vertically stacked wood. For larger mounds, a second tier of wood is stacked on top of the first, forming the "waist," and is finally capped with a third, shorter tier forming the "head" or hemispherical dome<sup>32</sup>. Once the main structural timber is stacked, the collier meticulously inspects the exterior for any gaps or voids. These voids are packed tightly with smaller branches, offcuts, and kindling to create a smooth, unified surface<sup>32</sup>.

## **Achieving the Hermetic Seal**

If the raw wood is exposed to the atmosphere during the extreme temperatures of the burn, it will rapidly incinerate. Therefore, the clamp must be sealed almost hermetically.

The entire wooden mound is first covered with a thick, overlapping organic buffer layer.

Historically, this consisted of green leaves, fresh pine boughs, ferns, or wet hay<sup>15</sup>. This layer serves a critical dual purpose: it prevents the outer dirt seal from filtering down into the clean wood and contaminating the final charcoal, and its high moisture content prevents the outer seal from immediately catching fire when the internal temperatures escalate<sup>15</sup>.

Over this organic buffer, a dense, continuous layer of soil, clay, or wet sand is applied, typically 4 to 6 inches thick<sup>5</sup>. In historic operations, colliers utilized *Stübbe* or *Lösche*—a blackened, recycled mixture of soil, fine ash, and charcoal dust recovered from previous burns<sup>29</sup>. This mixture packs densely to form a highly insulative, airtight crust. The central chimney is left completely open and uncovered at the top<sup>29</sup>. Finally, using a sharp stick or an iron rod, the collier punctures several small draft holes through the dirt seal around the absolute base of the mound, where the wood meets the soil<sup>29</sup>.

## **Ignition and Smoke Analysis**

The clamp is ignited from the top down, a counter-intuitive process that forces the heat to radiate downward against the natural upward convection of the draft, ensuring a slow, highly controlled pyrolysis front. The central chimney is filled to the brim with highly combustible dry kindling, wood shavings, and small sticks<sup>31</sup>. A generous quantity of glowing, red-hot coals—prepared in a separate auxiliary fire—is shoveled directly down into the chimney<sup>31</sup>.

The chimney is allowed to burn vigorously for several hours. The intense, localized heat begins to dry and ignite the inner ring of stacked wood. As the kindling in the chimney is consumed and drops downward, the collier continuously feeds more short logs into the top of the chimney to maintain a fierce central core of heat<sup>5</sup>. When the collier determines that the core of the mound is sufficiently ignited and the internal exothermic heat is self-sustaining—often indicated by a dull "knocking" or rumbling sound caused by the deflagration of trapped wood gas—the top of the chimney must be permanently sealed<sup>22</sup>. A flat stone or a heavy piece of wet turf is placed over the chimney hole, and it is buried beneath a thick layer of damp earth<sup>15</sup>.

Once the chimney is sealed, the air supply is restricted exclusively to the small draft holes at the

base<sup>29</sup>. The success of the charcoal yield now depends entirely on the constant vigilance of the collier. The clamp requires continuous 24-hour monitoring, sometimes for weeks depending on the scale of the mound<sup>15</sup>.

The primary diagnostic tool for monitoring the internal chemical state of the mound is the visual and olfactory analysis of the smoke escaping from the base draft holes and micro-fissures in the earthen seal.

| Phase of Pyrolysis                     | Visual and Olfactory Characteristics of Smoke                                                | Chemical Mechanism                                                                                                                                                      | Action Required by the Collier                                                                                                                     |
|----------------------------------------|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Phase 1: Dehydration</b>            | Thick, dense, bright white smoke. Odorless or slightly damp smell <sup>15</sup> .            | The endothermic vaporization of internal cellular moisture. The smoke is primarily composed of harmless water steam <sup>15</sup> .                                     | Maintain standard draft. Ensure the mound does not crack outward under internal steam pressure.                                                    |
| <b>Phase 2: Active Pyrolysis</b>       | Heavy, yellowish-white or brownish smoke. Highly acrid, sharply acidic smell <sup>29</sup> . | The destructive distillation of biopolymers. The smoke carries high concentrations of pyroligneous acid, volatile organic compounds, wood tar, and PAHs <sup>24</sup> . | Closely monitor temperature. The exothermic reaction is fully established and spreading through the wood mass.                                     |
| <b>Phase 3: Carbonization Complete</b> | Light, thin, nearly transparent, or distinctly bluish smoke. Minimal odor <sup>15</sup> .    | The volatile compounds have been entirely exhausted. The remaining material is an incandescent, highly pure carbon matrix burning cleanly <sup>15</sup> .               | The burn is complete in this sector. Close the adjacent draft holes immediately to prevent the pure carbon from oxidizing into ash <sup>15</sup> . |

During the burn, the wood will shrink dramatically—often losing 30% to 50% of its total

volume<sup>29</sup>. This extreme physical settling causes the rigid dirt crust to fracture and crack, threatening to let massive amounts of oxygen into the mound and incinerate the yield<sup>15</sup>. The collier must constantly walk across the surface of the active mound—a highly dangerous historical practice known as "jumping the pit"—to locate soft, collapsing voids and immediately seal any emerging cracks with fresh wet earth or clay<sup>29</sup>.

If the burn progresses unevenly due to wind or internal moisture pockets, the collier can manipulate the internal fluid dynamics by opening new draft holes on the slower side of the mound to pull the oxygen draft in that direction, while completely sealing the holes on the side that is burning too rapidly<sup>29</sup>.

## **Harvesting and the Hazard of Spontaneous Combustion**

When the entire perimeter of the mound emits thin, blue smoke, the pyrolysis process is universally complete<sup>15</sup>. The mound is now essentially a massive pile of glowing, red-hot carbon. To harvest the fuel, the mound must be completely suffocated. Every draft hole, crack, and fissure is sealed with a thick, heavy layer of wet mud and sand<sup>29</sup>. The objective is to achieve an absolute vacuum of atmospheric oxygen, arresting the combustion process entirely. The mound must be left to cool, a process that can take several days<sup>29</sup>.

Once entirely cold, the dirt crust is carefully raked away to reveal the charcoal. The yield is extracted sequentially, beginning at the outer edges (the foot) and working inward<sup>32</sup>. Pieces of wood that failed to completely carbonize—often found at the extreme edges of the mound—are separated and placed into smaller pits to be re-burned, a practice known historically as "foxing the brands"<sup>32</sup>.

A critical safety factor in charcoal harvesting is the severe phenomenon of spontaneous combustion (autoignition)<sup>60</sup>. Freshly manufactured, deeply desiccated charcoal is chemically highly reactive. When the earthen mound is breached and the fresh carbon is suddenly exposed to atmospheric oxygen, it undergoes intense physical and chemical adsorption<sup>61</sup>. This rapid oxidation of free radicals and aliphatic side chains on the vast, porous surface area of the charcoal generates immense localized heat<sup>61</sup>. If this heat cannot dissipate rapidly, it triggers a thermal runaway cascade, causing the supposedly "cold" charcoal to spontaneously burst into flames without any external ignition source<sup>60</sup>.

To mitigate this catastrophic risk, freshly extracted charcoal must be spread out in a thin, single layer in the open air to "cure" and stabilize for 24 to 48 hours<sup>29</sup>. Water must be kept immediately on hand to douse any individual fragments that begin to smolder or spark<sup>29</sup>. Never place freshly harvested charcoal directly into sealed bags, deep storage bins, or indoor areas, as the insulative properties of a deep pile will almost guarantee a spontaneous fire<sup>49</sup>.

## **Fuel Preparation and Forge Thermodynamics**

Once stabilized, the charcoal must be rigorously graded and sized for the forge. For optimal metallurgical performance, the charcoal should be mechanically fractured into uniform pieces roughly the size of a walnut or small egg (approximately 1 to 2 inches in diameter)<sup>63</sup>. This specific geometric sizing allows the pieces to lock together physically in the firepot, creating a dense, highly structured dome that traps radiant heat against the steel, while still leaving

adequate interstitial voids for the bellows blast to penetrate evenly<sup>49</sup>.

Large, intact logs of charcoal will leave massive geometric gaps in the fuel bed. These gaps allow the forced air from the bellows to bypass the combustion zone entirely, striking the steel workpiece directly and subsequently cooling or oxidizing it<sup>49</sup>. Conversely, the mechanical fracturing process will inevitably generate a significant volume of microscopic charcoal dust and fines<sup>49</sup>. This dust must be aggressively screened out and discarded; if poured into the forge, the dust will instantly clog the tuyere, suffocating the fire and creating an extreme occupational hazard of a flash fire or dust explosion<sup>49</sup>.

The quality of the final product can be rapidly verified through the "ring test." When a piece of properly carbonized, high-density hardwood charcoal is struck against a hard surface, such as the face of an anvil, it should produce a clear, crisp, metallic ringing sound, akin to striking ceramic or glass<sup>49</sup>. Charcoal that produces a dull, hollow thud or instantly crumbles into powder indicates incomplete pyrolysis, high residual moisture, or the utilization of an inferior, low-density softwood<sup>49</sup>.

## **Charcoal vs. Mineral Coal in the Forge**

Understanding the architectural and thermodynamic requirements of a solid-fuel forge requires a strict differentiation between the combustion mechanics of wood charcoal and bituminous mineral coal. Modern hobbyists often attempt to substitute one for the other within the same repurposed forge architecture—most commonly a heavy cast-iron brake drum—resulting in severe inefficiencies, excessive fuel consumption, and heavily oxidized steel<sup>8</sup>.

Bituminous (soft) coal requires a highly specific bottom-blast architecture. Because raw coal contains high levels of volatile organic compounds, moisture, and sulfur, it cannot be burned directly in the center of the fire<sup>1</sup>. The "green" coal must be banked around the perimeter of a deep firepot, where radiant heat cooks off the volatiles (producing thick smoke) and transforms the coal into coke<sup>1</sup>. Simultaneously, the non-combustible mineral impurities in the coal melt to form a glassy slag known as "clinker"<sup>1</sup>. The deep, conical shape of the bottom-blast firepot is designed explicitly to allow this heavy, molten clinker to sink safely below the air inlet, where it coalesces and can be extracted mechanically<sup>1</sup>.

Charcoal behaves entirely differently. It has already undergone the distillation process in the kiln; thus, it is effectively pre-coked and contains virtually no moisture, negligible sulfur, and minimal non-combustible ash, meaning it produces very little clinker<sup>9</sup>. Furthermore, charcoal possesses roughly one-tenth the specific density of bituminous coal<sup>8</sup>. If placed in a deep, bottom-blast coal firepot, the intense vertical air pressure will simply blow the lightweight charcoal out of the forge, creating a dangerous fountain of sparks<sup>8</sup>. The deep column of air will also cause the charcoal to combust far too rapidly, wasting the fuel and creating an excessively oxidizing atmosphere that aggressively burns the steel<sup>8</sup>.

## **The Side-Blast JABOD Architecture**

Therefore, charcoal demands a shallow, wide, side-blast architecture<sup>2</sup>. The most accessible, efficient, and historically accurate model for the hobbyist is the JABOD (Just A Box Of Dirt) forge, derived directly from traditional African and Asian smelting technologies<sup>1</sup>.

In this design, the structural housing consists of a simple wooden box, approximately 24 by 24 inches square and 7 to 9 inches deep<sup>1</sup>. This box is filled to the brim with a tightly tamped matrix of non-combustible earthen materials, ideally a mixture of heavy clay, loamy soil, and wood ash<sup>1</sup>. Into the center of this dirt matrix, the blacksmith excavates a shallow, oval trench, roughly 8 inches long, 4 inches wide, and 4 to 5 inches deep<sup>1</sup>.

The air is injected horizontally through a simple black iron pipe (the tuyere), typically 3/4-inch to 1-inch in internal diameter, driven through the side of the wooden box and flush with the wall of the dirt trench<sup>1</sup>. The tuyere must enter the trench 1 to 2 inches above the absolute bottom floor of the depression. This empty space below the air blast serves as the catch-basin for the minimal ash generated, ensuring the air pipe remains unobstructed<sup>1</sup>. Because there is no massive clinker formation to block vertical airflow, the complex iron plumbing manifolds required for coal forges are completely eliminated<sup>1</sup>.

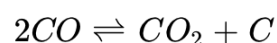
Furthermore, the JABOD circumvents the need for the massive, water-cooled cast-iron tuyere jackets found in industrial side-blast forges<sup>1</sup>. By recessing the tip of the inexpensive black iron pipe slightly behind the face of the dirt trench, the earth itself acts as the primary thermal insulator<sup>1</sup>. As the intense heat of the fire slowly oxidizes and melts the exposed tip of the pipe over dozens of hours of forging, the smith simply hacksaws off the degraded inch of metal and advances the pipe forward through the dirt—a highly modular, sacrificial engineering approach that maintains optimal side-blast thermodynamic performance<sup>1</sup>.

## The Boudouard Reaction and Atmospheric Control

The ultimate purpose of the forge is to achieve temperatures between  $1200^{\circ}\text{C}$  and  $1300^{\circ}\text{C}$  —the range necessary to plasticize the metal for forge welding—while simultaneously protecting the steel from destructive oxidation<sup>8</sup>. This delicate balance is dictated by the chemical atmosphere maintained within the charcoal mound.

When ambient atmospheric oxygen is forced into the active charcoal bed from the side-blast tuyere, it first encounters the lower combustion zone. Here, oxygen is highly abundant relative to the combusting carbon, creating an oxidizing atmosphere<sup>1</sup>. If a steel workpiece is placed at this depth, the excess oxygen reacts violently with the incandescent iron, rapidly forming a thick, brittle layer of iron oxide (forge scale) that destroys the mass and structural integrity of the metal<sup>1</sup>.

As the forced air travels higher through the incandescent carbon matrix, the carbon aggressively strips the oxygen, forming carbon dioxide ( $\text{CO}_2$ ) and carbon monoxide ( $\text{CO}$ )<sup>1</sup>. The precise equilibrium between the solid carbon fuel and the combustion gases is governed by the temperature-dependent Boudouard reaction:



At temperatures exceeding  $700^{\circ}\text{C}$  to  $1000^{\circ}\text{C}$ , this thermodynamic equilibrium shifts heavily

to favor the formation of carbon monoxide<sup>72</sup>. At a specific elevation in the fuel mound—ideally 3 to 4 inches above the tuyere blast—all free oxygen has been entirely consumed, creating a neutral-to-reducing atmosphere dominated by unburned  $CO$ <sup>1</sup>.

Carbon monoxide is a highly active chemical reducing agent. It aggressively seeks out oxygen to complete its transition into stable carbon dioxide; therefore, it acts as a chemical shield around the workpiece, actively scavenging ambient oxygen and even stripping oxygen atoms away from the surface of the steel itself<sup>15</sup>. This prevents the formation of scale and keeps the metal pristine, which is the absolute prerequisite for successful forge welding<sup>1</sup>.

This thermodynamic reality dictates the physical operation of the charcoal forge at the anvil. The smith cannot simply lay the steel on top of the fire. They must maintain a dense, unbroken mound of appropriately sized charcoal piled over the top of the workpiece to ensure the Boudouard reaction can run to completion, trapping radiant heat downward and maintaining the protective carbon monoxide blanket<sup>1</sup>.

By understanding the continuous, unbroken chain of pyrotechnology—from the localized silvicultural management of hardwood coppices, through the endothermic and exothermic balances of the earthen charcoal clamp, to the precise fluid dynamics and chemical reductions occurring within the side-blast dirt forge—the contemporary blacksmith reclaims a profound, historically accurate mastery over the fundamental mechanics of metallurgy.

## Works cited

1. 2-DIY Traditional Blacksmith Forge Guide.pdf
2. BTUs, coal vs coke vs charcoal vs wood - I Forge Iron, <https://www.iforgeiron.com/topic/31997-btus-coal-vs-coke-vs-charcoal-vs-wood/>
3. Evolution of Blast Furnace Iron Making - IspatGuru, <https://www.ispatguru.com/evolution-of-blast-furnace-iron-making/>
4. De Re Metallica - Project Gutenberg, <https://www.gutenberg.org/files/38015/38015-h/38015-h.htm>
5. Impact of charcoal production activities on soil profiles - ResearchGate, [https://www.researchgate.net/publication/30463453\\_Impact\\_of\\_charcoal\\_production\\_activities\\_on\\_soil\\_profiles\\_the\\_micromorphological\\_point\\_of\\_view](https://www.researchgate.net/publication/30463453_Impact_of_charcoal_production_activities_on_soil_profiles_the_micromorphological_point_of_view)
6. Charcoal: Types and Uses Explained | PDF - Scribd, <https://www.scribd.com/document/722865254/carbon-fuels-part-1>
7. Charcoal - Wikipedia, <https://en.wikipedia.org/wiki/Charcoal>
8. 2-The Forge\_ Building a Forced-Air Solid-Fuel Forge from Salvaged Materials.pdf
9. What is the best type of charcoal to use for blacksmithing? - Quora, <https://www.quora.com/What-is-the-best-type-of-charcoal-to-use-for-blacksmithing>
10. A Review of Pyrolysis Technologies and the Effect of Process ... - MDPI, <https://www.mdpi.com/1996-1073/16/19/6936>
11. (PDF) Experimental and Theoretical Investigation of Heat and Mass, [https://www.researchgate.net/publication/263160955\\_Experimental\\_and\\_Theoretical\\_Investigation\\_of\\_Heat\\_and\\_Mass\\_Transfer\\_Processes\\_during\\_Wood\\_Pyrolysis](https://www.researchgate.net/publication/263160955_Experimental_and_Theoretical_Investigation_of_Heat_and_Mass_Transfer_Processes_during_Wood_Pyrolysis)

12. Philosophy on Fuels - New Agrarian School,  
<https://www.newagrarianschool.org/about/philosophy-on-fuels/>
13. (PDF) Model Calculation of Heat Balance of Wood Pyrolysis,  
[https://www.researchgate.net/publication/309586234\\_Model\\_Calculation\\_of\\_Heat\\_Balance\\_of\\_Wood\\_Pyrolysis](https://www.researchgate.net/publication/309586234_Model_Calculation_of_Heat_Balance_of_Wood_Pyrolysis)
14. The performance of Abraham Darby I's coke furnace revisited, part 2,  
<https://www.hmsjournal.org/index.php/home/article/download/38/36/36>
15. Traditional Charcoal Making in Seychelles- Sarbon Lokal,  
<https://www.thecreolemeltingpot.com/traditional-charcoal-making-in-seychelles-sar-bon-lokal/>
16. Destructive Distillation of Wood Process | PDF | Charcoal | Acetic Acid,  
<https://www.scribd.com/document/587954586/docx>
17. (PDF) Modeling of pyrolysis in wood: A review - ResearchGate,  
[https://www.researchgate.net/publication/285025478\\_Modeling\\_of\\_pyrolysis\\_in\\_wood\\_A\\_review](https://www.researchgate.net/publication/285025478_Modeling_of_pyrolysis_in_wood_A_review)
18. Enthalpy changes during pyrolysis of biomass: Interpretation,  
<https://ideas.repec.org/a/eee/appene/v228y2018icp1985-1993.html>
19. Experimental Analysis of Reaction Heat Effects during Beech Wood,  
<https://pubs.acs.org/doi/10.1021/ef4001709>
20. Charcoal Production via Multistage Pyrolysis | Request PDF,  
[https://www.researchgate.net/publication/257445639\\_Charcoal\\_Production\\_via\\_Multistage\\_Pyrolysis](https://www.researchgate.net/publication/257445639_Charcoal_Production_via_Multistage_Pyrolysis)
21. Numerical Modelling of Wood Pyrolysis - DiVA portal,  
<https://www.diva-portal.org/smash/get/diva2:1095196/FULLTEXT01.pdf>
22. Charcoal Pits - Farmscape Ecology Program,  
<https://hvfarmscape.org/join-in/contribute-information/charcoal/>
23. (PDF) Redistillation of wood vinegar from peat swamp species,  
[https://www.researchgate.net/publication/348158224\\_Redistillation\\_of\\_wood\\_vinegar\\_from\\_peat\\_swamp\\_species](https://www.researchgate.net/publication/348158224_Redistillation_of_wood_vinegar_from_peat_swamp_species)
24. (PDF) Pyroligneous acids from carbonisation of wood and bamboo,  
[https://www.researchgate.net/publication/282974066\\_Pyroligneous\\_acids\\_from\\_carbonisation\\_of\\_wood\\_and\\_bamboo\\_Their\\_components\\_and\\_antifungal\\_activity](https://www.researchgate.net/publication/282974066_Pyroligneous_acids_from_carbonisation_of_wood_and_bamboo_Their_components_and_antifungal_activity)
25. The Chemistry of Smoked Foods: A review | Request PDF,  
[https://www.researchgate.net/publication/229989878\\_The\\_Chemistry\\_of\\_Smoked\\_Foods\\_A\\_review](https://www.researchgate.net/publication/229989878_The_Chemistry_of_Smoked_Foods_A_review)
26. Wood Smoke Flavor | Request PDF - ResearchGate,  
[https://www.researchgate.net/publication/229529739\\_Wood\\_Smoke\\_Flavor](https://www.researchgate.net/publication/229529739_Wood_Smoke_Flavor)
27. Study of volatile composition of an aqueous oak smoke preparation,  
[https://www.researchgate.net/publication/223233115\\_Study\\_of\\_volatile\\_composition\\_of\\_an\\_aqueous\\_oak\\_smoke\\_preparation](https://www.researchgate.net/publication/223233115_Study_of_volatile_composition_of_an_aqueous_oak_smoke_preparation)
28. Kilkerran Pyroligneous Acid Works 1845 to 1945 by David Courtney,  
<http://www.ayrshirehistory.org.uk/AcidWorks/acidworks.htm>
29. Charcoal pile - Wikipedia, [https://en.wikipedia.org/wiki/Charcoal\\_pile](https://en.wikipedia.org/wiki/Charcoal_pile)
30. Simple technologies for charcoal making - Slunik,  
[https://slunik.slu.se/kursfiler/SH0160/50040.1819/FAO\\_Forestry\\_Paper\\_41.pdf](https://slunik.slu.se/kursfiler/SH0160/50040.1819/FAO_Forestry_Paper_41.pdf)

31. One-Minute Essays - How to Make Charcoal - Penn State Engineering,  
[https://www.engr.psu.edu/mtah/essays/making\\_charcoal.htm](https://www.engr.psu.edu/mtah/essays/making_charcoal.htm)
32. Charcoal - Hopewell Furnace - National Park Service,  
<https://www.nps.gov/hofu/learn/historyculture/charcoal.htm>
33. Charcoal Production - energypedia,  
[https://energypedia.info/wiki/Charcoal\\_Production](https://energypedia.info/wiki/Charcoal_Production)
34. Effect of Firewood Moisture Content on Quality, Yield, and Economic,  
<https://www.mdpi.com/2673-3994/5/1/1>
35. CHARCOAL PRODUCTION IN TANZANIA USING IMPROVED,  
<https://idl-bnc-idrc.dspacedirect.org/bitstreams/9ee00d54-0a9c-4b0c-8dd3-a6a03d00f610/download>
36. how do I make charcoal? - Bladesmith's Forum,  
<https://www.bladesmithsforum.com/index.php?/topic/3087-how-do-i-make-charcoal/>
37. Coppice-with-standards. Underwood rotation = 20 years; Overwood,  
[https://www.researchgate.net/figure/Coppice-with-standards-Underwood-rotation-20-years-Overwood-rotation-100-years\\_fig1\\_235720297](https://www.researchgate.net/figure/Coppice-with-standards-Underwood-rotation-20-years-Overwood-rotation-100-years_fig1_235720297)
38. Silvicultural Guidelines for European Coppice Forests,  
<https://www.cabidigitallibrary.org/doi/pdf/10.5555/20193063061>
39. Intensive woodland management in the Middle Ages - PMC - NIH,  
<https://pmc.ncbi.nlm.nih.gov/articles/PMC5424077/>
40. Management of Coppice Stools - Forest Research,  
<https://cdn.forestresearch.gov.uk/2022/02/rin259.pdf>
41. Coppicing - Wikipedia, <https://en.wikipedia.org/wiki/Coppicing>
42. Improvement Cuttings in the Conversion of Pyrenean Oak (Quercus,  
<https://www.mdpi.com/1999-4907/14/3/575>
43. Forest flickers of history. Early modern woodland restoration and,  
<https://academic.oup.com/book/58200/chapter/481598204>
44. Siedlungsforschung. Archäologie – Geschichte - Uni Bamberg,  
[https://www.uni-bamberg.de/fileadmin/histgeo/ARKUM/Arkum\\_Zeitschrift\\_Siedlungsforschung/sf19-2001.pdf](https://www.uni-bamberg.de/fileadmin/histgeo/ARKUM/Arkum_Zeitschrift_Siedlungsforschung/sf19-2001.pdf)
45. Dissertation Jörg Müller Weihenstephan - mediaTUM,  
<https://mediatum.ub.tum.de/doc/603650/file.pdf>
46. (PDF) Charcoal kiln sites, associated landscape attributes and,  
[https://www.researchgate.net/publication/299132457\\_Charcoal\\_kiln\\_sites\\_associated\\_landscape\\_attributes\\_and\\_historic\\_forest\\_conditions\\_DTM-based\\_investigations\\_in\\_Hesse\\_Germany](https://www.researchgate.net/publication/299132457_Charcoal_kiln_sites_associated_landscape_attributes_and_historic_forest_conditions_DTM-based_investigations_in_Hesse_Germany)
47. Hardwood Charcoal Vs. Softwood Charcoal: Which To Choose?,  
<https://pnpcharcoal.com/choose-hardwood-charcoal-and-softwood-charcoal/>
48. Consequences of different sample drying temperatures for accuracy,  
<https://pmc.ncbi.nlm.nih.gov/articles/PMC7525458/>
49. Forge Fuel | Survival Wiki - Civilization Rebuild,  
<https://civilizationrebuild.com/phase-2-first-year/materials/forge-fuel>
50. A COMPARISON OF THREE WOOD SPECIES AND METHODS,  
<https://ejournal.aptklhi.org/index.php/ijfr/article/download/153/101/4193>

51. Hardwood Charcoal And Softwood Charcoal 2024,  
<https://vietnamcharcoal.com/hardwood-charcoal-and-softwood-charcoal/>
52. Joint UNDP/World Bank Energy Sector Management Assistance,  
<https://documents1.worldbank.org/curated/en/313791468756341100/pdf/multi-page.pdf>
53. Charcoal Production Business Plan Template - Avvale,  
<https://avvale.co.uk/pages/charcoal-production-business-plan-template>
54. How Dangerous Is Carbon Monoxide Exposure in the Workplace,  
<https://hazwoper-osha.com/blog-post/how-dangerous-is-carbon-monoxide-exposure-in-workplace>
55. Figure 2: The different stages of construction of charcoal mounds at,  
[https://www.researchgate.net/figure/The-different-stages-of-construction-of-charcoal-mounds-at-the-Ecomusee-de-Haute-Alsace\\_fig2\\_30463453](https://www.researchgate.net/figure/The-different-stages-of-construction-of-charcoal-mounds-at-the-Ecomusee-de-Haute-Alsace_fig2_30463453)
56. (PDF) 'Paleoenvironmental study of modern charcoal making activity,  
[https://www.researchgate.net/publication/376098229\\_'Paleoenvironmental\\_study\\_of\\_modern\\_charcoal\\_making\\_activity\\_on\\_forest\\_soils\\_in\\_the\\_Northern\\_Vosges\\_Mountains\\_Bitche\\_France\\_A\\_multidisciplinary\\_study\\_of\\_two\\_remaining\\_charcoal\\_platforms\\_and\\_associated](https://www.researchgate.net/publication/376098229_'Paleoenvironmental_study_of_modern_charcoal_making_activity_on_forest_soils_in_the_Northern_Vosges_Mountains_Bitche_France_A_multidisciplinary_study_of_two_remaining_charcoal_platforms_and_associated)
57. Primitive Charcoal Production : r/blacksmithing - Reddit,  
[https://www.reddit.com/r/blacksmithing/comments/17wh5qc/primitive\\_charcoal\\_production/](https://www.reddit.com/r/blacksmithing/comments/17wh5qc/primitive_charcoal_production/)
58. German-English Dictionary for Chemists - PDF Free Download,  
<https://epdf.pub/german-english-dictionary-for-chemists.html>
59. Understanding Carbon Through Charcoal Making — The Element of,  
<https://youblob.com/us/blueprints/understanding-carbon-through-charcoal>
60. (PDF) A critical investigation into spontaneous combustion in coal,  
[https://www.researchgate.net/publication/352920388\\_A\\_critical\\_investigation\\_into\\_spontaneous\\_combustion\\_in\\_coal\\_storage\\_bunkers](https://www.researchgate.net/publication/352920388_A_critical_investigation_into_spontaneous_combustion_in_coal_storage_bunkers)
61. Structural Evolution during Key Stages of Coal Spontaneous ... - PMC,  
<https://pmc.ncbi.nlm.nih.gov/articles/PMC13000658/>
62. Oxidation Characteristics of Functional Groups in Relation to Coal,  
<https://pmc.ncbi.nlm.nih.gov/articles/PMC7992153/>
63. Any tips for a beginner? Grill forge using lump charcoal : r/Blacksmith,  
[https://www.reddit.com/r/Blacksmith/comments/8un3c8/any\\_tips\\_for\\_a\\_beginner\\_grill\\_forge\\_using\\_lump/](https://www.reddit.com/r/Blacksmith/comments/8un3c8/any_tips_for_a_beginner_grill_forge_using_lump/)
64. Question for the charcoal users - I Forge Iron,  
<https://www.iforgeiron.com/topic/79514-question-for-the-charcoal-users/>
65. Chapter 10 - Using charcoal efficiently,  
<https://www.fao.org/4/x5328e/x5328e0b.htm>
66. Fundamental Study on the Carbonization Characteristics of Low,  
[https://www.researchgate.net/publication/271846310\\_Fundamental\\_Study\\_on\\_the\\_Carbonization\\_Characteristics\\_of\\_Low\\_Rank\\_Coal\\_Under\\_Low\\_Temperature\\_and\\_its\\_Application\\_on\\_Traditional\\_Blacksmith](https://www.researchgate.net/publication/271846310_Fundamental_Study_on_the_Carbonization_Characteristics_of_Low_Rank_Coal_Under_Low_Temperature_and_its_Application_on_Traditional_Blacksmith)
67. Aluminoslag Removing Flux has Different Effects with Different,  
<https://www.sata-fluxes.com/aluminoslag-removing-flux-has-different-effects-with-dif>

[ferent-forging-methods.html](#)

68. charcoal for smelt - Page 2 - Bladesmith's Forum,  
<https://www.bladesmithsforum.com/index.php?/topic/19398-charcoal-for-smelt/page/2/>
69. 5th International Meeting of Charcoal Analysis,  
<https://www.sapac.es/charcoal/saguntum/extra11/se11.pdf>
70. Mastery and Uses of Fire in Antiquity 9780773568556 - dokumen.pub,  
<https://dokumen.pub/mastery-and-uses-of-fire-in-antiquity-9780773568556.html>
71. How did ancient people melt steel with charcoal? : r/Blacksmith,  
[https://www.reddit.com/r/Blacksmith/comments/11e1qr1/how\\_did\\_ancient\\_people\\_melt\\_steel\\_with\\_charcoal/](https://www.reddit.com/r/Blacksmith/comments/11e1qr1/how_did_ancient_people_melt_steel_with_charcoal/)
72. Blast furnace - Wikipedia, [https://en.wikipedia.org/wiki/Blast\\_furnace](https://en.wikipedia.org/wiki/Blast_furnace)
73. Blast Furnace Reduction Processes Explained | PDF | Silicon,  
<https://www.scribd.com/document/903229765/Lec-2-Anis-1>