INTRODUCTION TO

NON-TRADITIONAL

MANUFACTURING SYSTEMS

Cutting Beyond Conventional Limits

Introduction — What is Non-Traditional Manufacturing?

NTM

Manufacturing processes that remove, shape, or join material using non-mechanical energy sources such as electrical discharge, laser light, chemical action, ultrasonic vibration, or electron beams.

1940s	NTM origins (EDM invented)
30%	of aerospace parts use NTM
$8B+	global NTM market (2024)

- **Electrical Discharge**
- **Laser Beam**
- **Abrasive Water Jet**
- **Electron Beam**
- **Plasma Arc**
- **Chemical/ECM**

Why Non-Traditional Manufacturing? — The Context

60 HRC
hardness limit
of conventional tools

0.001mm
NTM achievable
tolerance

Zero
tool contact
= zero tool wear

3x
harder materials
NTM can handle

Drivers for NTM Adoption

Hard & Brittle Materials

Ceramics, composites, titanium — conventional tools chip and wear rapidly.

Complex Internal Geometries

Cooling channels, micro holes, undercuts — impossible with rotating tools.

Very High Precision Needed

Sub-micron tolerances in MEMS, semiconductors, and medical implants.

No Residual Stress Required

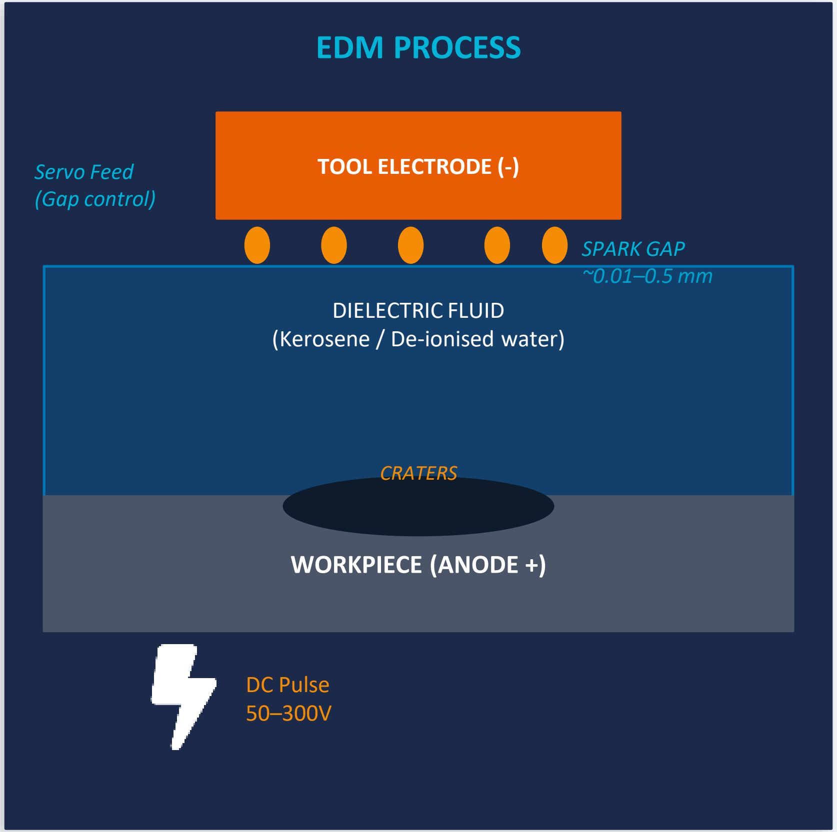
Heat-sensitive aerospace alloys must be shaped without mechanical stress.

Classification of Non-Traditional Manufacturing Processes

NTM PROCESSES

- **Thermal / Electric**
  - EDM
  - LBM
  - EBM
  - PAM
  - IBM
- **Mechanical / Abrasive**
  - USM
  - AJM
  - WJM
  - AWJM
- **Chemical / Electrochem**
  - CHM
  - ECM
  - PCM
  - ELP
- **Hybrid**
  - ECDM
  - ECSM
  - Laser+ECM

Core Process 1 — Electrical Discharge Machining (EDM)



Working Principle

Controlled spark discharges erode material from electrically conductive workpieces. Each spark removes 10^{-6} to 10^{-4} g of material.

Material Removal Rate

0.1–400 mm^3/min. Surface finish: Ra 0.4–6.3 µm. Tolerances to ±0.005 mm.

Best For

Hardened tool steels, carbides, Inconel. Complex cavities, mould making, micro-holes.

Key Limitation

Only works on electrically conductive materials. Recast layer may require post-processing.

Core Process 2 — Laser Beam Machining (LBM)

01	02	03	04	05
Laser Source	**Beam Shaping**	**Focusing Lens**	**Material Interaction**	**Assist Gas**
CO_2, Nd:YAG, Fibre laser	Collimator, expander, aperture	Focus to 0.01–0.1 mm spot	Melt, vaporise, or ablate zone	O_2, N_2 or Ar blows debris away

Laser Cutting

Thin to thick plates (0.5–25 mm). Speed up to 20 m/min. Used in automotive sheet metal.

Laser Drilling

Micro-holes to 0.1 mm diameter. Cooling holes in turbine blades — 100+ holes per blade.

Laser Marking

Permanent surface marking on any material. Medical device traceability (UDI standards).

Laser Welding

Deep penetration, minimal heat affected zone. Precision joining of dissimilar metals.

Laser focal spot: 0.01 mm | Cutting speed: up to 20 m/min | Energy efficiency: 10–30% | No tool wear

Core Process 3 — Ultrasonic Machining (USM)

USM MECHANISM

Ultrasonic Transducer	20–30 kHz, magnetostrictive
Velocity Transformer	Amplifies amplitude 10–75 µm
Tool (Soft Material)	Copper, brass, low-carbon steel
Abrasive Slurry	SiC or B_4C particles in water

Working Principle

Tool vibrates at ultrasonic frequency (20–30 kHz). Abrasive particles hammer the workpiece, fracturing it grain by grain.

Suitable Materials

Non-conductive, brittle materials: glass, quartz, ceramics, silicon, ferrite, precious stones.

Typical Applications

Watch jewels, ceramic filters, glass drilling, piezoelectric components, semiconductor slicing.

Process Parameters

MRR: 300–750 mm^3/min. Tolerance: ±0.013 mm. Surface finish Ra: 0.2–0.8 µm.

Core Processes 4 & 5 — Water Jet & Chemical Machining

ABRASIVE WATER JET (AWJM)

1 Pressure Pump

Water pressurised to 4,000 bar (60,000 psi)

2 Abrasive Mixing

Garnet abrasive mixed in venturi chamber

3 Focusing Nozzle

0.3–1.0 mm nozzle focuses supersonic jet

4 Cutting Action

Jet erodes material at 900+ m/s velocity

CHEMICAL / ELECTROCHEMICAL MACHINING

Chemical Machining (CHM)

Material dissolved by etchants ($FeCl_3$, HF, HNO_3). Maskant protects non-etched areas. Depth 0.025–12.5 mm.

Electrochemical Machining (ECM)

Anodic dissolution at 5–25V DC. Tool acts as cathode. 0.1–5 A/mm^2 current density. Mirror finish possible.

Photochemical Machining (PCM)

UV light exposes photoresist pattern. Etchant removes exposed metal. Used for precision metal parts.

Key Advantage

No heat, no stress, no burrs. Ideal for honeycomb aerospace panels, electronic leadframes, watch parts.

AWJM: 4,000 bar pressure | 900 m/s jet velocity | Cuts steel, stone, glass, composites, food — no heat

Core Processes 6 & 7 — Electron Beam & Plasma Arc

ELECTRON BEAM MACHINING (EBM)

Electron Gun	Heated tungsten cathode emits electrons
Accelerating Anode	50–200 kV acceleration — electrons reach 0.7c
Magnetic Focusing	Electromagnetic lenses focus beam to 0.01 mm
Deflection Coils	Programmed beam steering for complex paths
Vacuum Chamber	10^{-4} torr vacuum prevents electron scattering

Beam power density: 10^{15} W/m^2

PLASMA ARC MACHINING (PAM)

Mechanism

Ionised gas (plasma) at 5,000–30,000 °C melts and expels workpiece material at high velocity.

Gas Types

Nitrogen, argon, hydrogen, air. Choice affects cut quality, speed, and dross formation.

Applications

Cutting stainless steel, aluminium, titanium, and mild steel plates up to 100 mm thick.

vs Laser Cutting

PAM: cheaper equipment, faster on thick sections. Laser: better precision on thin sheets.

Process Selection — Comparative Overview

Process	Energy Type	Materials	MRR	Tolerance	Best Use
EDM	Electrical	Conductive only	Low–Med	±0.005 mm	Dies, moulds, micro-holes
LBM	Thermal	Any material	Med–High	±0.01 mm	Cutting, drilling, marking
USM	Mechanical	Brittle, non-cond.	Low	±0.013 mm	Ceramics, glass, silicon
AWJM	Kinetic	Any material	Med–High	±0.1 mm	Thick plates, composites
ECM	Electrochemical	Conductive only	High	±0.025 mm	Turbine blades, implants
EBM	Thermal	Any material	Very Low	±0.002 mm	Micro-holes, space parts
PAM	Thermal	Conductive metals	Very High	±0.5 mm	Thick plate cutting

Selection criteria: Material conductivity, hardness, geometry complexity, required tolerance, and production volume

Application 1 — Aerospace & Defence

30% of aerospace parts use NTM

200+ cooling holes per turbine blade

0.005mm EDM tolerance in Inconel

Turbine Blade Cooling Holes

EDM drills 200+ angled holes of 0.3–0.8 mm in Inconel turbine blades at angles impossible for drills. Each hole improves thermal efficiency by 2–3%.

Aircraft Panel Pocket Milling

Chemical milling removes material from aluminium fuselage panels, reducing weight by 30% while maintaining structural integrity without cutting forces.

Composite Part Cutting

AWJM cuts carbon fibre composites without delamination. No heat — preserves the polymer matrix critical for structural performance.

Rocket Nozzle Machining

EBM machines refractory alloys (W, Mo, Ta) used in rocket nozzles at >3,000°C service temperature — unmachinable by conventional means.

Gun Barrel Rifling

ECM cuts spiral rifling in gun barrels at 600+ mm/min with perfect surface finish and no residual stress that could cause fatigue cracks.

Application 2 — Medical Devices & Electronics

Orthopaedic Implants

ECM finishes joint implants (Ti6Al4V, CoCrMo) to Ra < 0.1 µm, reducing wear debris by 80%.

Semiconductor Wafer Dicing

Laser dicing cuts silicon wafers to 20 µm width with no cracking. 3,000 chips per 300 mm wafer.

Stent Manufacturing

Laser microcutting of 316L stainless steel tube creates coronary stents with 0.1 mm strut width.

MEMS Fabrication

ECM and photochemical machining create gyroscopes, accelerometers, and pressure sensors at microscale.

Neurosurgical Implants

EDM machines titanium neurostimulator housings to ±0.005 mm — critical for implant biocompatibility.

PCB Micro-Via Drilling

Laser drills 50–100 µm via holes in multilayer PCBs at 10,000 holes/second for HDI electronics.

Application 3 — Automotive & Energy Sectors

1970s	1990s	2000s	2010s	2020s
EDM for Die Making	LBM for Sheet Cutting	AWJM for Composites	Laser Welding EV Cells	Laser AM + EDM Hybrid

Fuel Injector Nozzles

EDM drills 0.12 mm precision holes in hardened steel nozzles. Hole geometry controls fuel atomisation and emissions.

EV Battery Laser Welding

Pulsed laser joins thin aluminium battery tabs at 200 mm/s with zero spatter. Critical for EV range and safety.

Wind Turbine Blades

AWJM trims carbon fibre composite blades up to 80 m long without delamination or heat distortion.

Solar Cell Scribing

Laser scribing creates precise isolation lines on thin-film solar panels, improving cell efficiency by 5–8%.

Advantages of Non-Traditional Manufacturing

No Tool Wear — Non-Contact Energy Removes Material

Machines Any Hardness — Ceramics, Carbides, Superalloys

Complex Geometries — Internal Channels, Micro-Features

High Precision — Sub-Micron Tolerances (±0.001 mm)

No Mechanical Stress on Workpiece

Material Independence

NTM can machine diamond, ceramics, and superalloys that shatter or deform conventional cutters instantly.

Automation Friendly

NTM is highly compatible with CNC, CAD/CAM, and robotic integration for lights-out manufacturing.

Waste Reduction

Precise material removal reduces scrap rates. Laser cutting wastes < 1 mm kerf vs 6 mm for saw cutting.

Challenges & Limitations of NTM Processes

High Capital Cost

Low Material Removal Rate

Energy Intensive

NTM LIMITATIONS

Thermal Damage (HAZ)

Skilled Operator Required

Limited Work-piece Size

Mitigations: Shared CNC platforms | Hybrid processes | Renewable energy | AI-assisted parameter optimisation

Conventional vs Non-Traditional Manufacturing — Head-to-Head

Parameter	Conventional	Non-Traditional	Winner
Material Hardness Limit	~60 HRC (tool fails)	No limit — hardness irrelevant	**NTM**
Geometric Complexity	Limited by tool access	Any geometry, including internal	**NTM**
Material Removal Rate	Very High (up to 500 cm^3/min)	Low–Medium (0.1–400 mm^3/min)	**Conventional**
Setup Cost	Low ($5,000–$50,000)	High ($50,000–$2M+)	**Conventional**
Tolerances	±0.01–0.1 mm	±0.001–0.05 mm	**NTM**
Tool Wear	Significant (expensive)	Minimal to none	**NTM**
Surface Finish	Ra 0.4–6.3 µm typical	Ra 0.01–3.2 µm possible	**NTM**
Conductive Materials Only	No restriction	EDM/ECM require conductivity	**Conventional**

Rule of thumb: Use NTM when material is too hard, geometry is too complex, or tolerance is too tight for conventional machining

Future Trends — NTM in the Era of Industry 4.0

NOW	2026	2028	2030	2035+
AI-Assisted EDM Optimisation	Hybrid Laser + ECM Centres	Nanoscale FIB Machining	In-Process AI Quality Control	Atomic-Scale Manufacturing

AI & Digital Twins

Real-time AI monitors EDM spark data, predicts tool erosion, and auto-optimises parameters — reducing setup time by 60%.

Hybrid NTM Machines

Single machines combine laser + ECM + EDM + AM in one setup. Fanuc's ROBODRILL already offers 5-axis + laser on one platform.

Micro/Nano NTM

Focused Ion Beam (FIB) machines features below 10 nm. Critical for quantum computing chips and NEMS devices.

Green NTM

Dry EDM, eco-friendly dielectrics, and solar-powered laser cutting reduce NTM's carbon footprint by 40%.

Additive + Subtractive

3D printing near-net shapes then NTM finishing for exact tolerances — a paradigm shift in titanium aerospace parts.

In-Line Quality AI

Optical and acoustic sensors feed real-time data to AI that detects defects during machining — zero inspection time.

Summary — Non-Traditional Manufacturing at a Glance

EDM
Electrical Discharge

LBM
Laser Beam

USM
Ultrasonic

EBM
Electron Beam

NTM SYSTEMS

PAM
Plasma Arc

AWJM
Water Jet

CHM
Chemical

ECM
Electrochemical

Applications: Aerospace 30% | Medical Devices | Electronics | Automotive | Energy | Defence

KEY TAKEAWAYS

01 NTM processes use non-mechanical energy (electrical, thermal, chemical, acoustic) to machine any material regardless of hardness.

02 Each NTM process has a specific energy type and material domain — EDM for conductors, USM for brittle non-conductors, LBM for any material.

03 Aerospace, medical devices, electronics, and energy sectors rely on NTM for parts that no conventional process can produce.

04 NTM advantages: no tool wear, complex geometries, sub-micron tolerances. Limitations: high cost, low MRR, skilled operators needed.

05 Future NTM will be AI-driven, hybrid, and nano-scale — enabling manufacturing of quantum devices and molecular-scale components.

"Non-traditional manufacturing is not an alternative — it is the only option when conventional engineering reaches its limits."