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The Science of Polyurethane Caster Wheels

How Chemistry, Formulation, and Manufacturing Determine Wheel Performance

Executive Summary

"Polyurethane" is not a single material. It's a family of chemistries with dramatically different performance characteristics. A polyurethane wheel that excels in one environment may fail catastrophically in another—not because of manufacturing defects, but because the wrong chemistry was specified for the application.

The three major polyurethane families—polyester, polyether (PPG), and polyether (PTMEG)—each have distinct strengths and weaknesses. Polyester resists oils and abrasion but fails when exposed to heat and moisture. Standard polyether resists water but has lower mechanical properties. PTMEG combines the best of both but costs more.

Beyond base chemistry, formulation variables—durometer, additives, cure profile—further tune performance for specific applications. A wheel optimized for food processing differs from one optimized for outdoor material handling, even if both are "polyurethane."

This paper explains the science behind polyurethane wheel performance: why chemistry matters, how formulations are tailored, what manufacturing quality factors affect service life, and how to match wheel chemistry to application requirements.

The Three Polyurethane Families

Polyurethane is formed by reacting polyols with diisocyanates. The type of polyol used determines the fundamental characteristics of the resulting material. Three polyol families dominate industrial polyurethane wheel production.

Polyester-Based Polyurethane

Polyester polyurethanes use polyester polyols as the soft segment. The ester linkages in the polymer backbone provide excellent mechanical properties.

Strengths: Superior tensile and tear strength. Excellent abrasion resistance. Good resistance to oils, fuels, and greases. Good long-term heat resistance in dry environments.

Critical weakness: Hydrolysis. The ester linkages are vulnerable to attack by water, especially at elevated temperatures. In hot, humid environments, moisture breaks the polymer chains, degrading mechanical properties over time. This can occur in as little as weeks in extreme conditions, or over 2+ years in moderate climates. Polyester urethanes are also susceptible to attack by bacteria and fungi.

Application fit: Excellent for dry industrial environments with oil exposure. Poor for outdoor use, humid climates, washdown environments, or food processing where moisture and heat combine.

Polyether-Based Polyurethane (PPG)

Standard polyether polyurethanes use polypropylene glycol (PPG) as the soft segment. The ether linkages are inherently stable against hydrolysis.

Strengths: Excellent water and humidity resistance—no hydrolysis concern. Good low-temperature flexibility. Superior microbe resistance. Better rebound and lower heat buildup than polyester.

Weaknesses: Lower tensile and tear strength than polyester. Reduced abrasion resistance. Less resistance to oils and solvents. Poorer performance under sustained high heat.

Application fit: Good for wet environments, washdown applications, and outdoor use where moisture exposure is constant. Acceptable for general-purpose applications where premium mechanical properties aren't required.

Polyether-Based Polyurethane (PTMEG)

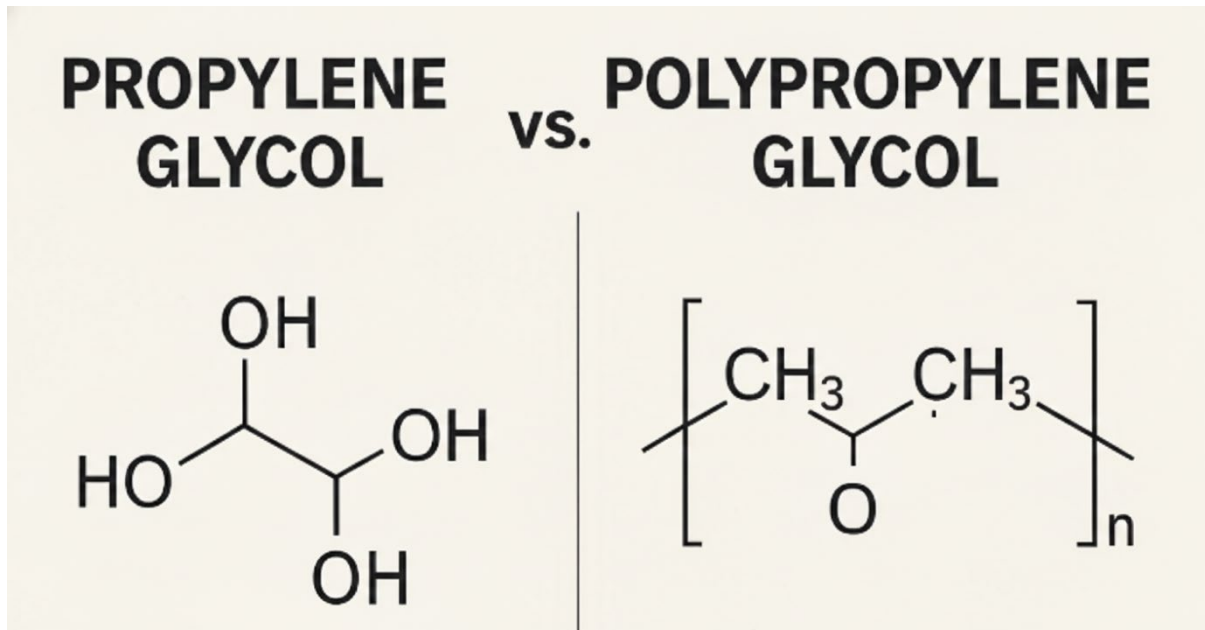
PTMEG (polytetramethylene ether glycol) polyurethanes represent the premium tier of polyether chemistry. The PTMEG soft segment provides mechanical properties approaching polyester while retaining polyether's hydrolysis resistance.

Strengths: At durometers above 80 Shore A, PTMEG approaches polyester's tensile and tear strength. Superior dynamic properties—better rebound (energy return), lower hysteresis (heat generation), better fatigue resistance. Excellent hydrolysis resistance. Good low-temperature performance. Outstanding performance in motion applications like wheels.

Weaknesses: Higher cost than PPG or polyester. Slightly lower oil resistance than polyester (though still good).

Application fit: The preferred choice for demanding wheel applications. Combines mechanical performance with environmental resistance. Particularly suited for high-cycle applications where dynamic properties matter.

Chemistry Comparison Summary



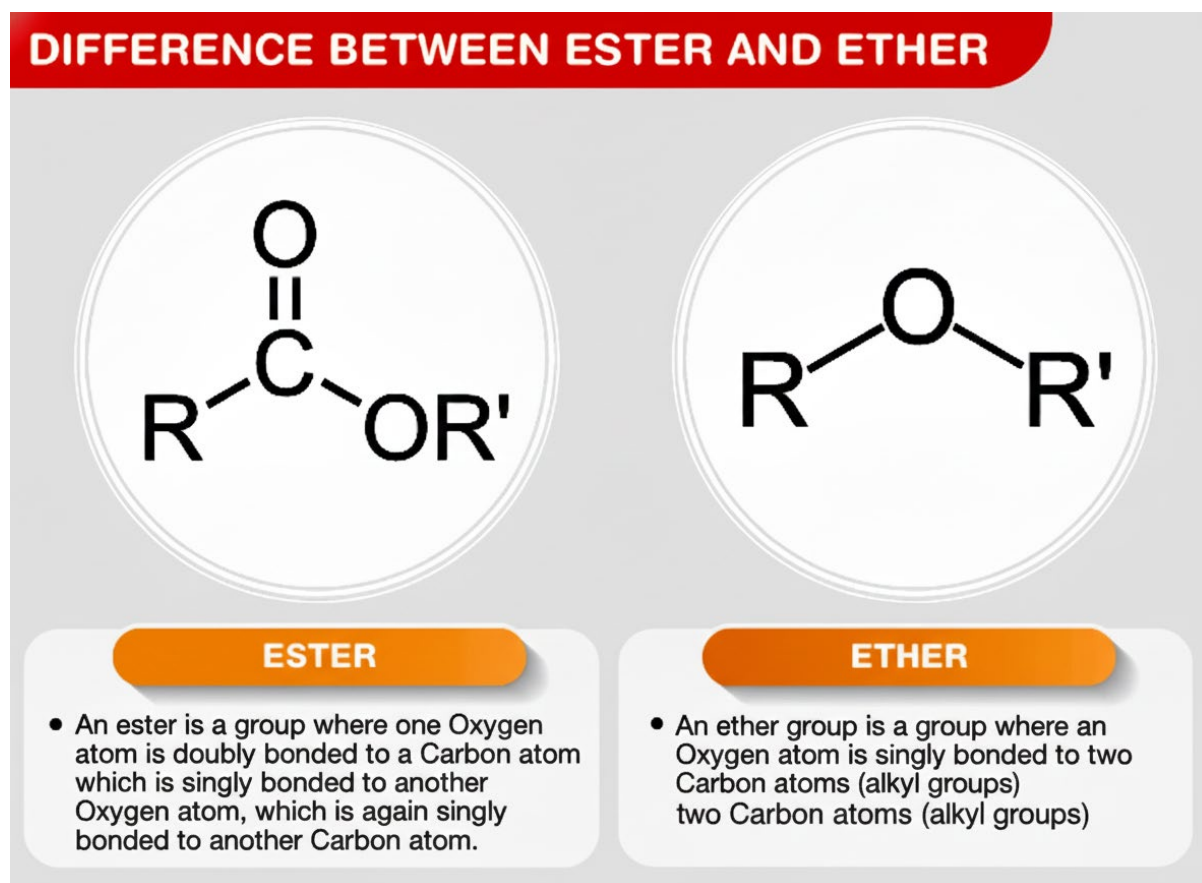
Property	Polyester	Polyether (PPG)	Polyether (PTMEG)
Tensile strength	35–55 MPa	25–40 MPa	40–60 MPa
Tear strength (Die C)	80–150 kN/m	50–100 kN/m	80–150 kN/m
Abrasion loss (DIN 53516)	15–40 mm ³	40–80 mm ³	20–50 mm ³
Bashore rebound	35–40%	40–45%	45–50%
Water/humidity resistance	Poor (hydrolysis)	Excellent	Excellent
Oil/fuel resistance	Excellent	Moderate	Good
Heat buildup in service	Higher	Lower	Lowest
Low-temperature flexibility	Moderate	Excellent	Excellent
Microbe resistance	Poor	Excellent	Excellent
Relative cost	Moderate	Lower	Higher

Why Chemistry Matters in Practice

The chemistry differences described above translate directly to field performance—and field failures. Understanding these mechanisms helps explain why wheels fail and how to prevent it.

The Hydrolysis Problem

Hydrolysis is the single most common cause of premature polyester polyurethane failure. The mechanism is straightforward: water molecules attack the ester linkages in the polymer backbone, breaking the chains and degrading mechanical properties.

The Molecular Difference:

Polyester linkage: $\text{--C--C--O--C(=O)--O--C--C--}$

The ester group (--C(=O)--O--) contains a carbonyl (C=O) adjacent to an oxygen. This carbonyl carbon is electrophilic—it attracts the oxygen in water molecules. When water attacks, the chain breaks at this point.

Polyether linkage: $\text{--C--C--O--C--C--O--C--C--}$

The ether group (--C--O--C--) has no carbonyl. The oxygen is bonded only to carbon atoms with no electrophilic center. Water has nothing to attack. The chain remains intact.

This is why polyether chemistry is inherently hydrolysis-resistant while polyester is not—the difference is literally one oxygen atom and a double bond, but the performance consequences are dramatic.

Heat accelerates the reaction dramatically. A polyester wheel that would last years in a dry, climate-controlled warehouse may fail in months in a humid outdoor environment or a hot washdown facility. The combination of heat and moisture is particularly destructive.

Symptoms of hydrolysis: The wheel becomes soft and tacky. Surface crazing appears. Chunks tear out easily. Eventually the tire separates from the core as the degraded material can no longer maintain the bond.

Prevention: Specify polyether (PPG or PTMEG) chemistry for any application involving moisture exposure, outdoor use, or elevated temperatures with humidity.

Dynamic Performance: Rebound and Heat Generation

Wheels in motion are constantly deforming and recovering as they roll. The energy efficiency of this cycle—how much compression energy returns as elastic rebound versus how much is lost as heat—varies significantly by chemistry.

PTMEG's superior rebound (45–50% Bashore resilience versus 35–40% for polyester) means less energy lost to heat, lower operating temperatures, easier rolling, and longer service life. For high-cycle applications—wheels that roll thousands of times per day—this difference compounds.

The practical impact: a PTMEG wheel running cooler under the same load lasts longer, rolls easier, and poses less risk of heat-induced bond failure than a polyester wheel.

How Hardness Is Controlled

Polyurethane hardness (durometer) significantly affects wheel performance. Softer wheels provide better shock absorption and noise reduction but have higher rolling resistance and lower load capacity. Harder wheels roll easier and carry more load but transmit more vibration and noise.

Understanding the Shore Scale

Durometer is measured on the Shore scale, with two ranges commonly used for polyurethane wheels:

Shore A measures softer materials. Most industrial polyurethane wheels fall in the 70–95 Shore A range. For reference: 60 Shore A feels like a rubber band or pencil eraser—soft and easily compressed. 95 Shore A feels like a shopping cart wheel—firm but with some give.

Shore D measures harder materials. Extra heavy-duty polyurethane wheels typically use 60–65 Shore D formulations. For reference: 60 Shore D feels like a hard hat or rigid plastic—minimal compression under finger pressure.

The scales overlap: approximately 95 Shore A equals 50 Shore D. But the magnitude of difference is important to understand—60 Shore D is dramatically

harder than 60 Shore A. They're not comparable numbers on different scales; they're measuring completely different material hardness ranges.

The Hardness/Capacity Trade-Off

Softer formulations compress more under load, which increases rolling resistance, heat generation, and creep (permanent deformation). As a rough guideline, **dropping from 95 Shore A to 80 Shore A may reduce practical dynamic load capacity by 25–40%**, depending on the specific formulation and application.

This is why softer wheels aren't simply "better" for shock absorption—the capacity penalty is real. A 95A wheel rated for 1,000 pounds might only be rated for 600–700 pounds at 80A, all else being equal.

Hardness is controlled through formulation, not just material selection. Three primary methods are used:

Plasticizers

Plasticizers are additives that don't chemically react with the polyurethane—they act as diluents, making the material softer. The advantage is simplicity and cost. The disadvantage is that plasticizers degrade the material's physical properties (tensile strength, tear resistance, abrasion resistance) because the added material contributes nothing to the polymer network.

Plasticizers can also migrate out of the material over time, causing the wheel to harden in service and potentially leaving residue on floors.

Chain Extension (Polyol/Diol/Triol Addition)

Adding polyols, diols, or triols to the formulation introduces long, flexible chains into the polymer network. Unlike plasticizers, these additives react with the polyurethane and become part of the structure. The result is a softer material that retains better mechanical properties than plasticizer-softened formulations.

This method allows significant hardness adjustment—dropping 20–30 durometer points—while maintaining acceptable performance.

Combined Approach

For very soft formulations (below 70 Shore A), combining chain extension with limited plasticizer achieves the target hardness with less property degradation than plasticizer alone would cause.

Hardness Increase

Increasing hardness beyond a base formulation's natural range is more limited—typically 3–5 points through curative and additive selection. Larger increases require switching to a different prepolymer system with inherently higher hardness.

Extra heavy-duty wheels for standing loads typically use 60–65 Shore D formulations—significantly harder than standard 90–95 Shore A wheels, with correspondingly higher creep resistance and load capacity.

Manufacturing Quality Factors

Even with the correct chemistry and formulation, manufacturing quality determines whether the wheel achieves its potential performance. Three factors are critical.

Bonding: The Tire-to-Core Interface

Most polyurethane wheel failures are bond failures—the tire separating from the core—rather than tire material failures. Bond integrity depends on both mechanical and chemical bonding.

Understanding Bond Failure:

When a wheel rolls under load, the tire deforms at the contact patch. This deformation creates shear stress at the tire-to-core interface—the tire is trying to "slide" relative to the core. If this shear stress exceeds bond strength, separation initiates.

Two bonding mechanisms resist this separation:

Mechanical bonding: The wheel core is designed with features that physically interlock with the polyurethane—pass-through holes that the urethane flows through, overhang geometries that the urethane flows around, knurled or textured surfaces that increase grip. These features provide mechanical resistance to separation even if the chemical bond weakens.

Chemical bonding: An adhesive primer applied to the core before casting creates covalent bonds between the polyurethane and the core material. The primer provides a surface that the polyurethane can chemically react with, creating molecular-level adhesion far stronger than mechanical interlock alone.

Quality manufacturers use both methods together. Mechanical bonding provides a safety margin if chemical bond degrades; chemical bonding provides strength beyond what mechanical features alone can achieve.

Post-Cure: Completing the Reaction

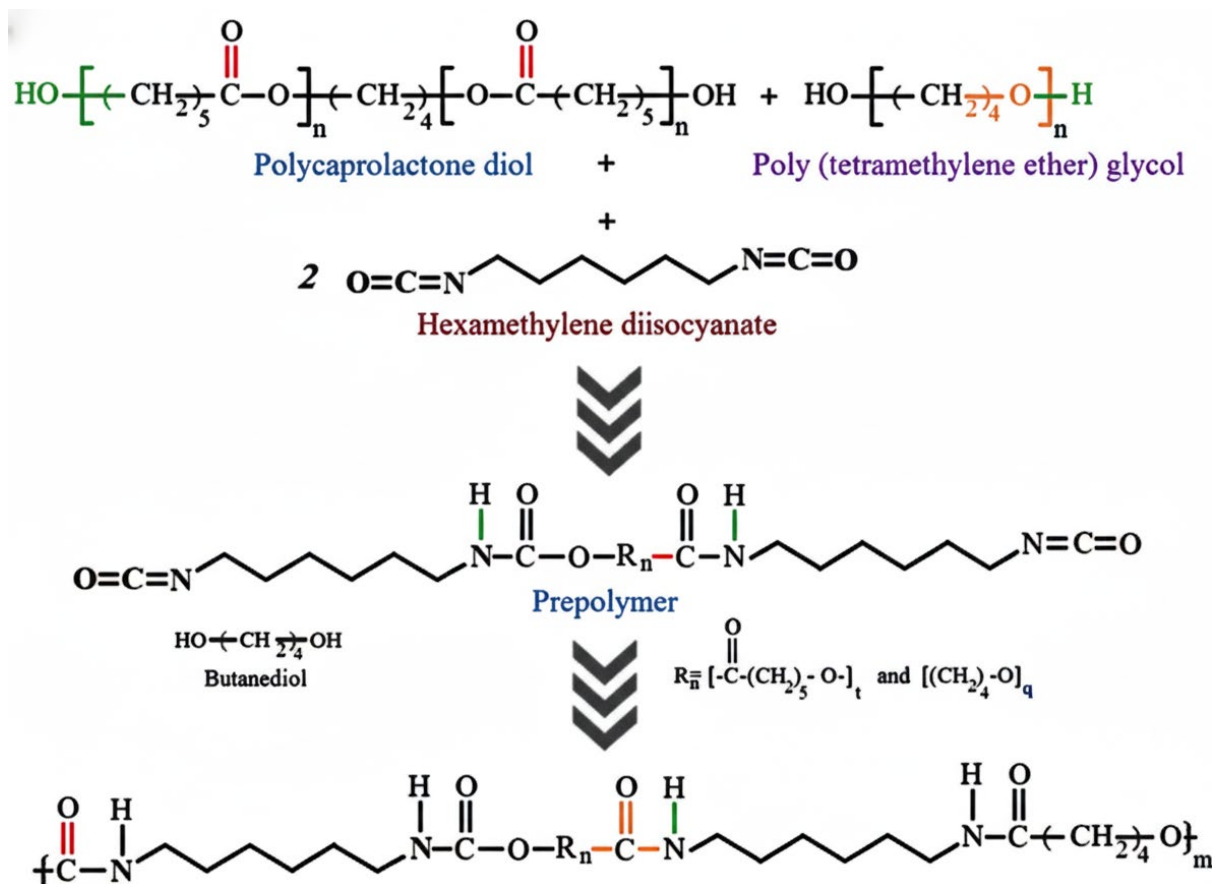


Figure 1 - **Polycaprolactone** (a polyester) and **Poly(tetramethylene ether) glycol** (PTMEG)

Cast polyurethane is formed by mixing two components—prepolymer and curative—that react to form the final material. The reaction begins immediately but doesn't complete during the initial molding cycle. When the wheel is demolded, it's solid but the reaction is still in progress.

Post-curing—holding the demolded wheel at elevated temperature (typically around 200°F) for several hours—drives the reaction toward completion. Without adequate post-cure, the material won't achieve its full mechanical properties.

The 30-Day Maturation

Even after post-cure, polyurethane continues developing properties for approximately 30 days. During this period, atmospheric moisture reacts with residual isocyanate groups in the material, completing the polymer network.

Wheels put into demanding service immediately after manufacturing may not perform to their full capability. Quality-conscious applications allow maturation time before heavy-duty use.

Chemical Compatibility

Polyurethane resists many chemicals that attack rubber, but it's not universally resistant. Understanding compatibility patterns helps specify the right chemistry for specific environments.

Generally Resistant (Both Ester and Ether)

Mineral oils, greases, and petroleum products (excellent to good resistance). Aliphatic hydrocarbons like hexane and heptane. Dilute acids and bases. Salt solutions. Vegetable oils and animal fats (good resistance, not excellent). Most common industrial lubricants.

Generally Not Resistant (Both Types Fail)

Strong solvents: acetone, MEK, toluene, xylene, chloroform, methylene chloride. Concentrated acids (nitric, sulfuric, phosphoric). Strong bases at elevated concentrations. Aromatic hydrocarbons. Most chlorinated solvents.

Chemistry-Dependent Resistance

Water and steam: Polyether excellent, polyester poor (hydrolysis).

Alcohols: Polyester slightly better than polyether, but neither is excellent with methanol.

Long-term heat with moisture: Polyether required; polyester will hydrolyze.

Application Guidance

Specify Polyester When:

The environment is dry and climate-controlled. Oil, fuel, or grease exposure is the primary chemical concern. Maximum abrasion resistance is needed. The application doesn't involve washdown, outdoor exposure, or high humidity. Cost optimization matters and PTMEG's premium isn't justified.

Specify Polyether (PPG) When:

Moisture exposure is constant (outdoor use, washdown environments). The application is cost-sensitive and premium mechanical properties aren't required. Microbe resistance matters (food processing without heavy chemical exposure). Low-temperature flexibility is needed.

Specify Polyether (PTMEG) When:

The application demands both mechanical performance and environmental resistance. High-cycle dynamic loading is involved (wheels moving constantly). Heat buildup from hysteresis must be minimized. The application justifies premium material cost through extended service life or critical performance requirements. You need the best overall wheel performance regardless of cost.

Consider Custom Formulation When:

Standard chemistries don't fully address the application requirements. Multiple conflicting demands must be balanced (e.g., oil resistance plus moisture resistance plus maximum load capacity). Unusual chemical exposures require specific compatibility testing. The application is critical enough to justify formulation optimization.

Conclusion

Polyurethane wheels are not commodities. The chemistry, formulation, and manufacturing quality that go into a wheel determine whether it lasts months or years in your specific application.

Specifying "polyurethane" without understanding the chemistry is like specifying "steel" without specifying the alloy—you might get what you need, or you might get something that fails in ways the generic specification never anticipated.

The right polyurethane wheel matches chemistry to environment (polyester for dry, polyether for wet), formulation to load requirements (durometer, additives), and manufacturing quality to service demands (bonding, cure, maturation).

The question isn't whether to use polyurethane.

The question is which polyurethane—because the wrong chemistry fails just as surely as the wrong material.

Understanding the science lets you make that choice deliberately, matching wheel chemistry to application demands instead of discovering the mismatch through premature failure.

About Caster City LLC

Caster City operates as a hybrid manufacturer-distributor based in Las Vegas, Nevada. Founded in the 1970s, the company maintains \$25 million in component inventory for rapid 2–3 day assembly and delivery while manufacturing custom polyurethane wheels in-house at our Texas facility.

Custom Polyurethane Capability: Caster City's polyurethane manufacturing isn't limited to off-the-shelf formulations. We produce custom wheels in any ester or ether blend—polyester, PPG polyether, PTMEG, or hybrid formulations—with enhanced additives tailored to specific application requirements. Whether the challenge is unusual chemical exposure, extreme load demands, temperature extremes, or unique performance requirements, our formulation capability allows us to engineer wheels for applications that standard products can't address.

Standard polyurethane wheels are available across our complete capacity range for common applications. For demanding or unusual requirements, our engineering team works with customers to specify or develop formulations matched to actual operating conditions.

For polyurethane chemistry consultation or custom formulation inquiries, contact Caster City at 800-501-3808 or sales@castercity.com.

This white paper describes polyurethane chemistry and manufacturing principles based on established polymer science. Specific formulation recommendations depend on detailed application analysis.