

ZnoNova Technical & Commercial Dossier

Technical Dossier: Pd/MWCNT Catalyst for Solid-State Hydrogen Storage Systems

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1. Executive Summary & Core Physical Specifications

This technical dossier details the empirical kinetics, thermodynamic parameters, and engineering integration profiles for **Pd/MWCNT (Palladium on Multi-Walled Carbon Nanotubes)**, a peer-reviewed catalytic additive engineered for magnesium-based solid-state metal hydride hydrogen storage.

Commercial magnesium hydride (MgH_2) offers a very high theoretical gravimetric hydrogen capacity (7.6 wt%). However, pure magnesium suffers from sluggish sorption kinetics and an excessively high thermodynamic barrier, demanding temperatures exceeding 400 °C to desorb hydrogen at practical rates.

By decorating high-aspect-ratio multi-walled carbon nanotubes with uniform nano-scale palladium particles (5 wt% Pd / 95 wt% MWCNT, Product Grade: **TP-121101**), the catalyst creates a synergistic "hydrogen spillover" network across magnesium alloy matrices (AZ31 and AZ61). This breakthrough accelerates hydrogen diffusion, significantly lowers the apparent activation energy barrier, and enables stable reversible cycling.

Physical & Chemical Properties (Per-Batch CoA Baseline)

Property	Specification / Measured Metric	Analytical Standard
Product Grade	TP-121101	Internal Code
Composition	5.0 wt% ± 0.2 wt% Palladium (Pd) / 95.0 wt% MWCNT	ICP-OES & TGA
Pd Particle Size	2.5 – 5.0 nm (Narrow mono-dispersion)	HR-TEM
MWCNT Outer Diameter	10 – 20 nm	FE-SEM
MWCNT Length	5 – 15 μm	FE-SEM
Specific Surface Area (BET)	≥ 220 m ² /g	Nitrogen Adsorption (BET)
Purity (Carbon + Noble Metal)	> 99.0 wt%	ICP-MS & Combustion Analysis
Moisture Content	< 0.5 wt%	Karl Fischer Titration
Appearance	Fine, free-flowing black powder	Visual Inspection

2. Peer-Reviewed Empirical Sorption Kinetics & Thermodynamics

The quantitative performance data below originates directly from rigorous peer-reviewed investigations published in leading energy storage journals: * **Journal of Energy Storage** 179 (2026) 123907 (AZ31 Magnesium Alloy System) * **Fuel** 425 (2026) 139436 (AZ61 Magnesium Alloy System) * **J. Research Updates in Polymer Science**, 2023, 12, 203-207 (Pd/Graphene Noble Metal Composites)

Benchmark Comparison: Pure AZ31 vs. AZ31 + 5 wt% Pd/MWCNT

The benchmark measurements below evaluate ball-milled AZ31 alloy with and without 5 wt% Pd/MWCNT catalyst:

Performance Metric	Pure AZ31 Alloy	AZ31 + 5 wt% Pd/MWCNT	Empirical Advantage
Reversible H ₂ Capacity (375 °C)	6.15 wt%	6.89 wt%	+12.0% (~99% of corrected theoretical capacity)
Reversible H ₂ Capacity (325 °C)	2.20 wt%	3.48 wt%	+58.2% increase at reduced operating temperatures
Absorption Time (t ₉₀ @ 375 °C)	662 s	446 s	32.6% faster saturation speed
Desorption Time (t ₉₀ @ 375 °C)	1,155 s	735 s	36.4% faster release speed
Desorption Apparent Activation Energy (E _d)	132.7 kJ/mol	98.5 kJ/mol	-25.8% (~26%) reduction in thermal desorption barrier
Absorption Apparent Activation Energy (E _a)	73.5 kJ/mol	61.2 kJ/mol	-16.7% reduction in hydride formation barrier
Hydride Formation Enthalpy (ΔH)	-68.76 kJ/mol H ₂	-61.97 kJ/mol H ₂	Thermodynamically favorable phase transition
20-Cycle Reversible Retention	Rapid capacity loss (<60% at cycle 10)	>98.5% capacity retention	Stable across 20 complete sorption cycles

Key Technical Finding: Empirical trials demonstrate that an **AZ31 matrix with 5 wt% Pd/MWCNT** yields superior kinetic acceleration and reversible capacity compared to an **AZ61 matrix with 3 wt% catalyst**, making AZ31 the recommended commercial alloy host for stationary applications.

3. Engineering Mass Accounting & Sizing Comparison

In stationary hydrogen energy storage and industrial microgrids, solid-state metal hydrides eliminate the hazards and parasitic compressor energy demands of 350–700 bar compressed gas cylinders.

Compared to conventional room-temperature rare-earth hydrides (AB_5 and AB_2 intermetallics), the ZnoNova modified magnesium system delivers a **5-fold to 6-fold reduction** in active material mass.

Comparative Mass Required to Store 1.0 kg of Pure Hydrogen (H_2)

Storage Technology	Working Medium	Effective Capacity (wt%)	Active Material Mass per 1 kg H_2	System Weight Factor
Conventional Rare-Earth Alloy	AB_5 (LaNi ₅ -type)	1.1 – 1.4 wt%	70.0 – 90.0 kg	1.0x (Baseline)
Conventional Titanium-Iron Alloy	AB (TiFe-type)	1.5 – 1.8 wt%	55.0 – 66.0 kg	~0.75x
ZnoNova Modified Magnesium System	AZ31 + 5 wt% Pd/MWCNT	6.2 – 6.89 wt%	14.5 – 16.1 kg	~0.21x (79% weight reduction)

Note: Total balance-of-plant (BOP) weight includes heat exchanger tubing, thermal oil jackets, phase change thermal storage, and vessel containment.

4. Validated Industrial Use Cases

The high desorption temperature requirement (325–375 °C) dictates that Pd/MWCNT-modified magnesium systems are strictly engineered for high-temperature thermal integration:

1. Industrial Waste-Heat Recovery Microgrids (Steel, Cement, Glass, Chemical)

- High-temperature industrial facilities routinely reject flue gases and radiant heat at 300–500 °C into the atmosphere.

- By routing this waste heat through the heat-exchanger jackets of AZ31+Pd/MWCNT metal hydride vessels, stored green hydrogen can be released on demand with zero secondary heating electricity consumption.
- **Key Economic Benefit:** Levelized cost of hydrogen storage (LCOS) drops below \$1.50/kg H₂ when paired with zero-cost industrial waste heat.

2. Thermally Driven Metal Hydride Hydrogen Compressors

- Replaces mechanical piston and diaphragm compressors.
- By thermally cycling the metal hydride bed between 150 °C (absorption at low pressure, e.g., 5–10 bar from an electrolyzer) and 350 °C (desorption), hydrogen is discharged at pressures exceeding 50–150 bar without moving parts, lubricants, or vibration.

3. Stationary Renewable Island Microgrids

- Ideal for seasonal or weekly long-duration energy storage (LDES) paired with concentrated solar power (CSP) or high-temperature heat pumps.

5. Strict Operating Boundaries & Non-Applications

In compliance with ZnoNova's scientific integrity standards, the following technological boundaries must be observed:

1. Not for Vehicular or Portable Ambient Storage:

- Desorption requires a sustained operating temperature of 325 °C – 375 °C.
- It will NOT release hydrogen at ambient room temperature (25 °C) or standard automotive coolant temperatures (80–90 °C). Do NOT deploy in passenger EVs, drones, or consumer electronics.

2. Atmospheric Inert Handling:

- Finely ball-milled magnesium hydride powders are pyrophoric when exposed to air or moisture. All handling, milling, vessel packing, and transfer must be executed strictly under argon (Ar) or high-purity nitrogen (N₂) atmospheres (O₂ < 1 ppm, H₂O < 1 ppm).

3. Cathode vs. Anode Electrocatalysis:

- Companion noble-metal catalyst (Nano-Pt) functions strictly as an alkaline or PEM Hydrogen Evolution Reaction (HER) cathode catalyst. It does not replace anode iridium (Ir/IrO_x) in Oxygen Evolution Reaction (OER).
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6. Intellectual Property & Patent Status

The core formulation and synthesis technologies are protected under valid invention patents:

- **Taiwan Invention Patent TW I866520:** *"Hydrogen storage apparatus and graphene noble metal composite material"* (Valid through **2043-10-05**).
 - **Taiwan Invention Patents:** TW I732556, TW I404562.
 - **Chinese Invention Patents:** CN ZL200910150067.2, CN ZL200910163167.9.
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7. Sample Dispatch Protocol & Academic Sponsorship Program

ZnoNova and Top Nano Technology maintain a dedicated **Global Academic & Corporate R&D Evaluation Program**:

Phase 1: Rapid Evaluation Aliquots (5g – 50g)

- **Eligibility:** Verified university departments, national energy laboratories, and accredited corporate R&D divisions.
- **Package:** 5.0 g hermetically vacuum-sealed vial of TP-121101 Pd/MWCNT catalyst powder, accompanied by:
 1. Per-batch Certificate of Analysis (CoA) with ICP-OES Pd loading confirmation;
 2. HR-TEM and FE-SEM morphology micrographs;
 3. Standard High-Energy Ball Milling (HEBM) integration SOP with recommended rotation speed, ball-to-powder ratio (BPR), and milling duration.
- **Turnaround:** Sample documentation approved within 1–2 business days.

Phase 2: Pilot Line & Semi-Bulk Supply (500g – 10kg)

- Provided for bench-scale reactor vessels and pilot heat-exchanger prototyping.
 - Delivered with full batch consistency reports under standard commercial mutual NDA.
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Technical Inquiries & Sample Requests

To initiate sample dispatch or receive customized system mass simulations:

Alex

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