



Pumped HYDROelectric Storage in post MINEd areas to support regional net-zero emission energy systems development

## **D4.1: Analysis and Evaluation of Green Polymers for Sustainable Pipe Materials: Development of a Suitable Formulation**

**Project:** HYDROMINE – Pumped HYDROelectric Storage in post MINEd areas

**Work Package:** WP4 – Design of an environmentally friendly pipeline system for small pumped storage units

**WP Leader:** Technical University of Chemnitz (CUT)

**Task:** T4.1 – Selection, evaluation, characterization of pipelines materials

**Contributing Partners:**

- CUT (Technical University of Chemnitz) – Coordinator
- WUST (Wroclaw University of Science and Technology) – Participant
- UP (University of Petrosani) – Participant
- FRAUNHOFER (Fraunhofer Institute for Machine Tools and Forming Technology) – Participant

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### **Executive Summary**

This deliverable provides guidelines for the selection and development of environmentally friendly polymers as pipe materials for small pumped hydroelectric storage (PHS) systems. The guidelines cover the evaluation of plastic types, the selection of materials from renewable resources, the testing and characterisation of materials, and the development of formulations considering mechanical properties.

Three candidate materials have been identified and evaluated: Braskem SGF4950 (bio-based HDPE), Braskem SGM9450F (bio-based HDPE), and SABIC PE B5823 (conventional HDPE). The analysis encompasses the evaluation of plastic types suitable for pipe applications, the selection criteria for materials derived from renewable resources, and the comprehensive characterization requirements necessary for developing formulations that meet the mechanical and environmental demands of small PHS systems.

Key findings indicate that bio-based high-density polyethylene (HDPE) derived from sugarcane ethanol offers significant environmental advantages—approximately 5 kg CO<sub>2</sub> equivalent reduction per kilogram of material compared to fossil-based alternatives—while maintaining full technical compatibility with established pipe manufacturing and joining processes. The guidelines presented herein establish the framework for material selection, characterization, and formulation development to ensure optimal performance of pipeline systems in demanding outdoor environments.



## 1. Introduction

### 1.1 Background and Motivation

Pumped hydroelectric storage (PHS) systems represent a critical technology for energy storage and grid stabilization. However, the development of small and medium-scale PHS systems for post-mining and quarry sites faces significant technical and environmental challenges. Among these, the design and material selection for pipeline systems constitute a fundamental engineering problem.

Conventional pipeline materials, predominantly derived from fossil fuels, contribute substantially to the carbon footprint of PHS infrastructure. The HYDROMINE project addresses this challenge by developing dedicated, small-scale PHS units specifically designed for post-mining environments, with particular emphasis on environmentally friendly pipeline systems.

The pipeline system in small PHS installations connects the upper and lower water reservoirs and represents both a critical structural component and a significant material cost. For the HYDROMINE demonstrator, these pipelines will be large in diameter, considerable in length, and subject to prolonged exposure to outdoor environmental conditions without protective covering. This demanding application profile necessitates materials that combine technical performance, environmental sustainability, practical manufacturability, and economic viability.

### 1.2 Scope and Objectives

This deliverable (D4.1) represents the consolidated outcome of Task 4.1 (T4.1: Selection, evaluation, characterization of pipelines materials), conducted collaboratively by the Technical University of Chemnitz (CUT, coordinator), Wrocław University of Science and Technology (WUST), University of Petrosani (UP), and Fraunhofer Institute for Machine Tools and Forming Technology (FRAUNHOFER).

The deliverable establishes guidelines for the selection and development of environmentally friendly polymers as pipe materials for small PHS systems. The specific objectives are to:

- 1 Evaluate available plastic types and polymeric materials suitable for pipe applications in water conveyance systems
- 2 Establish selection criteria for materials derived from renewable resources
- 3 Define characterization and testing requirements for candidate materials
- 4 Specify mechanical property requirements for PHS pipeline applications
- 5 Provide recommendations for formulation development and optimization
- 6 Document the rationale for material selection in the HYDROMINE project

This work builds upon the collective expertise of the partner institutions in materials science, polymer engineering, and manufacturing technology.



### 1.3 Application Context

The HYDROMINE pipeline system operates under the following conditions:

- **Fluid:** Fresh water or treated water
- **Operating pressure:** Dependent on reservoir elevation difference and system design (typically 5-50 bar for small systems)
- **Diameter range:** Large diameter pipes (200-400 mm typical for demonstrator)
- **Length:** Extended lengths requiring field joining
- **Installation environment:** Outdoor, unprotected exposure to weather
- **Climate exposure:** Full UV radiation, temperature cycling, precipitation, wind
- **Lifespan:** Minimum 30-50 years
- **Installation method:** Field assembly with fusion welding

## 2. State-of-the-Art: Bio-based Polymers for Pipe Applications

### 2.1 Overview of Polymer Types for Pipe Applications

Thermoplastic polymers have become the dominant material class for modern pipe systems due to their favorable combination of mechanical properties, processability, and cost-effectiveness. The primary polymers used in pipe applications include:

**High-Density Polyethylene (HDPE)** represents the most widely used thermoplastic for pressure pipe systems. HDPE offers excellent chemical resistance, low moisture absorption, and superior flexibility compared to rigid thermoplastics. Its molecular structure—characterized by high crystallinity and linear chains with minimal branching—provides the strength necessary for pressure applications while maintaining adequate toughness.

**Polyvinyl Chloride (PVC)** has historically been used for non-pressure and low-pressure applications, though its use is declining due to environmental concerns regarding chlorine content and additives.

**Polypropylene (PP)** offers higher temperature resistance than HDPE but lower impact resistance at low temperatures, limiting its application to specific niches.

**Polyethylene Terephthalate (PET)** and other polyesters provide superior stiffness and temperature resistance but at significantly higher cost.

For small PHS systems, **HDPE emerges as the optimal choice** due to its established track record in water conveyance, proven long-term durability, compatibility with fusion welding technologies, and favorable cost-performance ratio.

### 2.2 Bio-based Polymers: Production and Sustainability

Bio-based polymers represent a paradigm shift in material sourcing, replacing fossil fuel feedstocks with renewable biomass. The most advanced bio-based polymer technology currently



at commercial scale is **bio-based polyethylene (bio-PE)**, which is chemically identical to conventional polyethylene but derived from renewable sources.

### 2.2.1 Production Process: Sugarcane to Bio-based HDPE

The production pathway for bio-based HDPE from sugarcane represents a sophisticated integration of agricultural, biochemical, and chemical engineering processes:

**Agricultural Phase:** Sugarcane cultivation occurs in Brazil on approximately 1% of the national territory, with 95% of expansion occurring on degraded pastureland rather than primary forest. The crop actively absorbs CO<sub>2</sub> from the atmosphere during growth, establishing a carbon sequestration phase that is fundamental to the lifecycle environmental benefit.

**Ethanol Extraction:** Modern sugarcane mills process the harvested cane through crushing and fermentation to produce both sugar (for food applications) and ethanol. Critically, these mills are energy self-sufficient, utilizing the leftover cane fibers (bagasse) as fuel for their own energy generation. This integration eliminates external energy requirements and represents a significant sustainability advantage.

**Ethylene Conversion:** The extracted ethanol undergoes dehydration to produce ethylene (C<sub>2</sub>H<sub>4</sub>), the fundamental monomer for polyethylene synthesis. This conversion is conducted at Braskem's Renewable Ethylene Plant, which has operated since 2010.

**Polymerization:** The ethylene is then polymerized using standard industrial processes to produce polyethylene with identical chemical structure and properties to conventional HDPE. No modification of existing polymerization technology is required.

### 2.2.2 Environmental Performance: Life Cycle Assessment

Comprehensive life cycle assessments (LCA), verified by third-party certification bodies, demonstrate substantial environmental advantages of bio-based HDPE:

**Carbon Footprint Reduction:** The production of one kilogram of bio-based HDPE (derived from sugarcane ethanol) results in approximately 5 kg CO<sub>2</sub> equivalent reduction compared to conventional fossil-based HDPE. This benefit arises from two mechanisms: (1) the carbon sequestration during sugarcane growth, and (2) the energy self-sufficiency of the production process.

To contextualize this environmental benefit, the carbon savings from producing one tonne of bio-based HDPE (5 tonnes CO<sub>2</sub> equivalent reduction) are equivalent to:

- The annual carbon emissions of approximately 0.6 European residents (based on average per capita emissions of 8 tonnes CO<sub>2</sub>/year)
- 2 economy-class return flights between Europe and Brazil (approximately 2.5 tonnes CO<sub>2</sub> per return flight)
- Driving approximately 33,000 km in an average European passenger car (based on 150 g CO<sub>2</sub>/km)



**Certification and Verification:** Bio-based HDPE from Braskem carries multiple sustainability certifications:

- **ISCC PLUS** (International Sustainability and Carbon Certification)
- **BONSUCRO** (Sustainable Sugarcane Production)
- Third-party verified LCA studies

**Recyclability:** Bio-based HDPE is 100% recyclable and compatible with existing plastic waste streams. From a material perspective, it is chemically indistinguishable from conventional HDPE, allowing seamless integration into established recycling infrastructure.

### 2.3 Comparative Material Properties

The following table presents key properties of the three candidate materials evaluated for the HYDROMINE project:

Property	Unit	SGF4950	SGM9450F	SABIC B5823
<b>Material Type</b>	—	Bio-HDPE	Bio-HDPE	Conventional HDPE
<b>Bio-based Content</b>	%	96	96	0
<b>Density</b>	g/cm <sup>3</sup>	0.956	0.952	~0.96
<b>Melt Flow Rate</b>	g/10 min	0.34	0.33-9.3	0.16
<b>Tensile Strength at Yield</b>	MPa	29	40	~30
<b>Tensile Strength at Break</b>	MPa	20	85	~20
<b>Flexural Modulus</b>	MPa	1290	750-870	~1200
<b>Impact Strength (Izod)</b>	kJ/m <sup>2</sup>	8	200	~8
<b>Vicat Softening Temperature</b>	°C	128	125	~128



Property	Unit	SGF4950	SGM9450F	SABIC B5823
Primary Application	–	Blow-molding	Film extrusion	Blow-molding
Processability	–	Excellent	Excellent	Excellent
CO <sub>2</sub> Reduction	kg CO <sub>2</sub> e/kg	~5	~5	0

### 3. Material Selection Criteria

#### 3.1 Technical Requirements for PHS Pipeline Systems

The material selection process begins with establishing the technical requirements that any candidate material must satisfy:

**Pressure Resistance:** The pipeline must withstand the hydrostatic pressure generated by the elevation difference between reservoirs. For typical small PHS systems (50-200 m elevation difference), this translates to operating pressures of 5-20 bar. The material must provide an adequate safety factor, typically 1.25-1.5 for plastic pipes.

**Mechanical Strength:** The material must exhibit sufficient tensile strength, flexural rigidity, and impact resistance to withstand both static pressure loads and dynamic stresses from water hammer effects during pump startup and shutdown.

**Environmental Stress Crack Resistance (ESCR):** Exposure to certain chemical compounds and mechanical stress can initiate stress cracking in polymers. The material must demonstrate adequate ESCR to prevent premature failure in field conditions.

**Thermal Stability:** The material must maintain mechanical properties across the anticipated temperature range (typically -10°C to +60°C for outdoor installation in temperate climates).

**UV Resistance:** Unprotected outdoor exposure to ultraviolet radiation causes photodegradation of polymers. The material must either possess inherent UV resistance or be formulated with UV stabilizers (typically carbon black).

**Long-term Durability:** The pipeline system must maintain functionality for 30-50 years with minimal maintenance. This requires resistance to hydrolysis, oxidation, and environmental degradation.

**Weldability:** The material must be compatible with fusion welding technologies (butt fusion or electrofusion) to enable field assembly of extended pipe lengths.



### 3.2 Environmental Sustainability Criteria

Beyond technical performance, material selection must incorporate environmental considerations:

**Carbon Footprint:** Preference for materials with reduced lifecycle greenhouse gas emissions. Bio-based alternatives demonstrating 50%+ reduction compared to conventional materials are prioritized.

**Renewable Sourcing:** Materials derived from sustainably managed renewable resources are preferred over fossil fuel-based alternatives.

**Recyclability:** The material should be recyclable at end-of-life, preferably compatible with existing recycling infrastructure.

**Production Sustainability:** The manufacturing process should minimize energy consumption, avoid toxic additives, and demonstrate responsible sourcing practices.

**Certifications:** Third-party verified sustainability certifications (ISCC PLUS, BONSUCRO, etc.) provide assurance of environmental claims.

### 3.3 Economic Viability Criteria

**Material Cost:** The raw material cost must be compatible with project economics. For large-diameter pipes, material cost represents a significant portion of total system cost.

**Processing Cost:** The material must be processable using standard industrial equipment without requiring specialized or expensive processing technology.

**Installation Cost:** Compatibility with established joining and installation methods minimizes field labor costs and training requirements.

**Lifecycle Cost:** Total cost of ownership, including installation, maintenance, and eventual replacement, should be favorable compared to alternatives.

## 4. Characterization of Candidate Materials

### 4.1 Braskem SGF4950: Bio-based HDPE for Blow-Molding

#### Material Identity and Sourcing

Braskem SGF4950 is a high-density polyethylene copolymer specifically developed for blow-molding applications. The material is produced from sugarcane ethanol sourced from sustainably managed plantations in Brazil, with 96% of the carbon content derived from renewable biomass (verified per ASTM D6866).

#### Technical Properties

The material exhibits well-balanced properties between impact resistance and stiffness, combined with high environmental stress cracking resistance. Key mechanical properties include:

- Density: 0.956 g/cm<sup>3</sup>
- Melt flow rate (190°C/2.16 kg): 0.34 g/10 min



- Tensile strength at yield: 29 MPa
- Tensile strength at break: 20 MPa
- Flexural modulus: 1290 MPa (relatively high stiffness)
- Izod impact strength: 8 kJ/m<sup>2</sup>
- Vicat softening temperature: 128°C

### **Processing Characteristics**

SGF4950 is designed for compression molding and extrusion blow-molding processes. The material demonstrates excellent processability with good flow characteristics. For pipe extrusion applications, the material can be processed on standard HDPE extrusion equipment with appropriate temperature and pressure control.

### **Environmental Performance**

- Bio-based content: 96% (ASTM D6866 verified)
- Carbon footprint reduction: ~5 kg CO<sub>2</sub>e per kg compared to fossil HDPE
- Certifications: ISCC PLUS, BONSUCRO
- Recyclability: 100% compatible with existing HDPE recycling streams
- Thermal stability: Comparable to conventional HDPE

### **Suitability for PHS Pipelines**

SGF4950 presents an excellent candidate for PHS pipeline applications. The high flexural modulus (1290 MPa) provides good resistance to bending stresses during installation. The material's environmental stress cracking resistance ensures durability in field conditions. The established blow-molding heritage indicates mature processing technology, though extrusion for pipe production would require process development.

## **4.2 Braskem SGM9450F: Bio-based HDPE for Film Extrusion**

### **Material Identity and Sourcing**

Braskem SGM9450F is a high-density polyethylene produced using bimodal technology for high molecular weight film extrusion applications. Like SGF4950, it is derived from sugarcane ethanol with 96% bio-based carbon content.

### **Technical Properties**

The bimodal molecular weight distribution provides a unique balance of properties:

- Density: 0.952 g/cm<sup>3</sup>
- Melt flow rate (190°C/5 kg): 0.33 g/10 min; (190°C/21.6 kg): 9.3 g/10 min
- Tensile strength at break (MD/TD): 85/35 MPa
- Elongation at break (MD/TD): 590/740%
- Tensile strength at yield (MD/TD): 40/30 MPa
- Secant modulus 1%: 750/870 MPa
- Dart drop impact: 200 g/F50
- Sealing initial temperature: 125°C



### **Processing Characteristics**

SGM9450F is optimized for blown film extrusion with excellent tenacity and impact resistance. The bimodal technology enables easier processing and superior mechanical properties compared to monomodal alternatives. The material can be adapted for pipe extrusion applications with appropriate process parameters.

### **Environmental Performance**

- Bio-based content: 96% (ASTM D6866 verified)
- Carbon footprint reduction: ~5 kg CO<sub>2</sub>e per kg
- Certifications: ISCC PLUS, BONSUCRO
- Recyclability: 100% compatible with HDPE recycling
- Thermal stability: Comparable to conventional HDPE

### **Suitability for PHS Pipelines**

SGM9450F offers exceptional toughness and elongation at break, providing superior impact resistance and flexibility. These properties are advantageous for field installation where pipes may experience handling stresses. The high elongation (590-740%) indicates good ductility, which is beneficial for pressure surge absorption. The material's proven performance in demanding film applications suggests excellent durability potential for pipe applications.

## **4.3 SABIC PE B5823: Conventional HDPE for Blow-Molding**

### **Material Identity and Sourcing**

SABIC PE B5823 is a conventional high-density polyethylene developed for blow-molding of consumer packaging. The material is produced from fossil fuel feedstocks using standard petrochemical processes.

### **Technical Properties**

- Density: ~0.96 g/cm<sup>3</sup>
- Melt flow rate (190°C/2.16 kg): 0.16 g/10 min
- Tensile strength at yield: ~30 MPa
- Tensile strength at break: ~20 MPa
- Flexural modulus: ~1200 MPa
- Impact strength: ~8 kJ/m<sup>2</sup>
- Vicat softening temperature: ~128°C
- ESCR: Good

### **Processing Characteristics**

B5823 is a monomodal HDPE with excellent processability on standard blow-molding and extrusion equipment. The low melt flow rate (0.16 g/10 min) indicates a relatively high molecular weight, providing good mechanical properties.

### **Environmental Performance**

- Bio-based content: 0% (fossil-derived)
- Carbon footprint: Baseline for comparison



- Recyclability: 100% compatible with HDPE recycling
- Thermal stability: Standard HDPE performance

### **Suitability for PHS Pipelines**

While B5823 meets the technical requirements for pipe applications, it lacks the environmental sustainability advantages of bio-based alternatives. The material serves primarily as a technical benchmark and cost reference point. However, SABIC offers bio-based variants within their TRUCIRCLE portfolio that could provide similar environmental benefits to the Braskem materials.

## **5. Guidelines for Material Characterization and Testing**

### **5.1 Mechanical Property Testing**

Comprehensive mechanical characterization is essential to validate material suitability for pressure pipe applications:

#### **Tensile Testing (ISO 527 / ASTM D638)**

- Determine tensile strength at yield and at break
- Measure elongation at yield and at break
- Establish stress-strain curves for material behavior analysis
- Minimum sample size: 5 specimens per material

#### **Flexural Testing (ISO 178 / ASTM D790)**

- Measure flexural modulus and flexural strength
- Assess material stiffness and bending resistance
- Relevant for pipe installation and support conditions

#### **Impact Testing (ISO 180 / ASTM D256)**

- Conduct Izod impact testing at multiple temperatures (-10°C, 23°C, 60°C)
- Assess toughness and resistance to brittle failure
- Evaluate temperature-dependent performance

#### **Pressure Testing (ISO 1167 / ASTM D1598)**

- Conduct hydrostatic pressure testing on pipe samples
- Determine burst pressure and failure mode
- Establish pressure rating and safety factors
- Minimum duration: 1000 hours at 80% of burst pressure

#### **Environmental Stress Crack Resistance (ESCR) Testing (ISO 6259 / ASTM D1693)**

- Evaluate resistance to stress-induced cracking
- Test in presence of surfactant solutions
- Assess long-term durability under combined stress and chemical exposure



## **5.2 Environmental Durability Testing**

### **UV Resistance Testing (ISO 4892 / ASTM G154)**

- Conduct accelerated weathering tests
- Measure mechanical property retention after UV exposure
- Evaluate effectiveness of UV stabilizers (carbon black)
- Minimum duration: 500-1000 hours
- Monitor tensile strength retention (target: >80% after 1000 hours)

### **Hydrolysis Resistance Testing (ISO 62 / ASTM D570)**

- Measure water absorption after immersion
- Assess dimensional stability
- Evaluate long-term performance in aqueous environment

### **Thermal Cycling Testing**

- Subject materials to repeated temperature cycling (-10°C to +60°C)
- Assess dimensional stability and mechanical property retention
- Minimum 50 cycles

### **Outdoor Weathering Testing**

- Deploy material samples in outdoor environment
- Monitor mechanical property changes over 6-12 months
- Assess real-world performance under natural conditions

## **5.3 Processability Testing**

### **Extrusion Testing**

- Conduct pilot extrusion trials to produce pipe samples
- Optimize temperature, pressure, and cooling parameters
- Evaluate surface quality and dimensional consistency
- Assess processing stability and repeatability

### **Fusion Welding Testing (ISO 13953 / ASTM D2657)**

- Conduct butt fusion welding trials on extruded pipe samples
- Establish optimal welding parameters (temperature, pressure, time)
- Evaluate weld quality through visual inspection and mechanical testing
- Conduct tensile testing on welded samples
- Target: Weld strength  $\geq$  90% of base material strength

### **Thermal Properties Characterization**

- Determine melting point and crystallization behavior (DSC)
- Assess thermal stability during processing



- Evaluate thermal expansion coefficients

## 6. Mechanical Property Requirements for PHS Pipeline Systems

### 6.1 Design Pressure and Safety Factors

The design of PHS pipelines must account for the hydrostatic pressure generated by the water column height. For a typical small PHS system with 100 m elevation difference:

**Hydrostatic Pressure:**  $P = \rho \times g \times h = 1000 \text{ kg/m}^3 \times 9.81 \text{ m/s}^2 \times 100 \text{ m} \approx 981 \text{ kPa} \approx 9.8 \text{ bar}$

For safety and operational margin, the design pressure is typically set at 1.5 times the maximum operating pressure, yielding a design pressure of approximately 15 bar for this example.

### 6.2 Pressure Rating and Hoop Stress

For thin-walled cylindrical pressure vessels (pipes), the hoop stress is given by:

$$\sigma = (P \times D) / (2 \times t)$$

where P is internal pressure, D is outer diameter, and t is wall thickness.

For HDPE pipes, the allowable hoop stress is typically limited to 10-12 MPa based on long-term hydrostatic strength and safety factors. This translates to specific diameter-to-thickness ratios (SDR values) that define pressure ratings.

### 6.3 Minimum Property Requirements

Based on the application requirements and industry standards (ISO 4427 for PE pressure pipes), the following minimum mechanical properties are specified:

Property	Minimum Value	Test Method
Tensile Strength at Yield	20 MPa	ISO 527
Tensile Strength at Break	15 MPa	ISO 527
Elongation at Break	350%	ISO 527
Flexural Modulus	600 MPa	ISO 178
Izod Impact Strength (23°C)	5 kJ/m <sup>2</sup>	ISO 180



Property	Minimum Value	Test Method
Vicat Softening Temperature	120°C	ISO 306
Hydrostatic Strength (1000h @ 20°C)	≥80% of initial	ISO 1167
ESCR (Condition A, 50h)	≥ 50 h	ISO 6259
UV Resistance (after 1000h ASTM G154)	≥80% strength retention	ASTM G154

#### 6.4 Long-term Performance Considerations

**Creep and Stress Relaxation:** HDPE exhibits time-dependent deformation under sustained load. Design must account for creep through appropriate safety factors and pressure ratings. Long-term hydrostatic strength testing (ISO 1167) provides the basis for establishing safe operating pressures.

**Environmental Degradation:** Exposure to UV radiation, temperature cycling, and water can gradually degrade polymer properties. The inclusion of UV stabilizers (carbon black) and the selection of inherently stable materials (HDPE) are critical for long-term performance.

**Fatigue Resistance:** Cyclic pressure variations (from pump operation) can induce fatigue failure. While HDPE generally exhibits good fatigue resistance, this should be verified through appropriate testing.

### 7. Formulation Development Recommendations

#### 7.1 Base Resin Selection

Based on the evaluation presented in Section 4, **both Braskem bio-based HDPE grades (SGF4950 and SGM9450F) are recommended as preferred base resins** for the HYDROMINE pipeline system. The selection between these two should be based on:

- **SGF4950** is recommended if prioritizing flexural stiffness and established blow-molding heritage
- **SGM9450F** is recommended if prioritizing toughness, impact resistance, and elongation properties

Both materials offer identical environmental benefits (~5 kg CO<sub>2</sub>e reduction per kg) and are fully compatible with fusion welding technologies.



## 7.2 Additive Formulation

While bio-based HDPE provides the environmental foundation, formulation optimization through targeted additives is necessary to achieve optimal performance:

### UV Stabilizers (Carbon Black)

- **Recommended concentration:** 2-3% by weight
- **Function:** Absorbs UV radiation and prevents photodegradation
- **Benefit:** Enables unprotected outdoor use with 50+ year lifespan
- **Selection:** High-quality furnace carbon black (e.g., N330 grade) provides optimal balance of UV protection and optical properties
- **Note:** Carbon black imparts black color, which is standard for outdoor pipe applications

### Antioxidants

- **Recommended types:** Hindered phenols and phosphites
- **Concentration:** 0.5-1.5% by weight
- **Function:** Prevents thermal and oxidative degradation during processing and service life
- **Selection:** Establish compatibility with base resin and other additives

### Processing Aids

- **Type:** Slip agents and flow enhancers (if needed)
- **Concentration:** 0.1-0.5% by weight
- **Function:** Improve extrusion processability and surface quality
- **Note:** Evaluate necessity through pilot extrusion trials

### Nucleating Agents (Optional)

- **Function:** Enhance crystallinity and mechanical properties
- **Consideration:** Evaluate impact on processing parameters and final properties

## 7.3 Formulation Development Process

The formulation development should follow a systematic approach:

### Phase 1: Baseline Formulation

- Establish baseline formulation with UV stabilizer (carbon black 2-3%)
- Conduct preliminary extrusion trials
- Evaluate mechanical properties and processability

### Phase 2: Optimization

- Vary carbon black concentration (1.5-3.5%) to optimize UV resistance vs. optical properties
- Evaluate antioxidant type and concentration
- Assess processing aid necessity through extrusion trials
- Conduct mechanical property testing per Section 5.1



### Phase 3: Environmental Testing

- Conduct UV resistance testing (ISO 4892) on optimized formulation
- Perform hydrolysis and thermal cycling tests
- Evaluate long-term property retention

### Phase 4: Pilot Production

- Produce pilot quantities of optimized formulation
- Conduct full-scale extrusion trials for pipe production
- Perform fusion welding trials and validation
- Collect data for scale-up to production quantities

## 7.4 Quality Control and Specifications

The final formulation should be documented with precise specifications:

- Base resin type and grade (e.g., Braskem SGF4950)
- Additive types, concentrations, and suppliers
- Processing parameters (temperature, pressure, cooling)
- Mechanical property targets and acceptance criteria
- Traceability and batch documentation requirements

## 8. Recommendations and Next Steps

### 8.1 Material Selection Recommendation

Based on the comprehensive evaluation presented in this document, the following recommendations are made:

**Primary Recommendation:** Braskem bio-based HDPE (SGF4950 or SGM9450F) as the base material for the HYDROMINE pipeline system formulation. This selection is justified by:

- 7 **Environmental Performance:** ~5 kg CO<sub>2</sub>e reduction per kilogram compared to conventional HDPE, verified through third-party LCA
- 8 **Technical Compatibility:** Full compatibility with established pipe extrusion and fusion welding technologies
- 9 **Long-term Durability:** Proven performance in demanding applications with 50+ year lifespan potential
- 10 **Sustainability Certifications:** ISCC PLUS and BONSUCRO certifications provide assurance of environmental claims
- 11 **Recyclability:** 100% compatible with existing HDPE recycling infrastructure
- 12 **Lifecycle Advantage:** Superior environmental profile over entire product lifecycle



**Secondary Consideration:** SABIC PE B5823 or equivalent conventional HDPE may be evaluated as a cost-optimized alternative, with consideration of bio-based variants within SABIC's TRUCIRCLE portfolio as a compromise option.

## 8.2 Formulation Development Path

The formulation development should proceed through the phased approach outlined in Section 7.3:

- 13 **Months 1-2:** Establish baseline formulation with carbon black UV stabilizer; conduct preliminary characterization
- 14 **Months 2-3:** Optimize additive package; conduct mechanical property testing
- 15 **Months 3-4:** Perform environmental durability testing; validate UV resistance
- 16 **Month 4+:** Pilot production and fusion welding validation

## 8.3 Integration with WP4 Tasks

This deliverable (D4.1) establishes the material selection and formulation guidelines that will inform subsequent WP4 tasks:

- **T4.2 (Pipe Geometry Design):** Material properties from D4.1 inform pressure rating calculations and wall thickness design
- **T4.3 (Formulation Matrix):** D4.1 recommendations guide the development of the formulation matrix and test plan
- **T4.4 (Laboratory Tests):** D4.1 specifies the testing protocols and acceptance criteria for laboratory evaluation
- **T4.5 (Recipe Optimization):** D4.1 establishes the baseline formulation for optimization activities

## 8.4 Sustainability and Circular Economy Considerations

Beyond the technical and environmental benefits documented in this deliverable, the material selection contributes to broader sustainability objectives:

**Carbon Neutrality:** The use of bio-based HDPE derived from sustainably managed sugarcane plantations contributes to carbon-neutral or carbon-negative lifecycle profiles, supporting the HYDROMINE project's sustainability goals.

**Circular Economy:** The full recyclability of HDPE within existing waste streams enables a circular material flow, reducing the need for virgin material extraction and processing.

**Post-Mining Land Restoration:** The HYDROMINE project's focus on post-mining sites aligns with the bio-based material's origin in restored degraded lands in Brazil, creating a symbolic and practical connection between material sourcing and project objectives.



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- 14 Plastics Europe. (2024). "Plastics – the Facts 2024." Industry Report.\n15. European Commission. (2024). "Circular Economy Action Plan." Retrieved from <https://ec.europa.eu/\n\n--\n\n##> Appendix A: Material Data Sheets\n\n### A.1 Braskem SGF4950 – Technical Data Summary\n\nSee attached datasheet: SGF4950-enUS-ISO.pdf\n\n### A.2 Braskem SGM9450F – Technical Data Summary\n\nSee attached datasheet: SGM9450F-enUS-ASTM.pdf\n\n### A.3 SABIC PE B5823 – Technical Data Summary\n\nTo be provided upon availability.\n\n--\n\n\*\bDocument prepared by: Technical University of Chemnitz (CUT), WP4 Leadership  
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