

# Comparative Analysis of Batch and Continuous Processes

Optimized Large-Scale (4000 kg/day) Reaction, Crystallization, and Filter-Drying Process

## A Case Study

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This article presents real-world data. To protect confidentiality, the customer data and product details will remain undisclosed during this discussion. The following information illustrates how continuous processing can substantially improve production performance across various dimensions.

We have highlighted our capabilities in process intensification and optimization by eliminating multiple unit operations and reducing the overall process steps from 11 to just 6. This transformation has led to notable improvements, including increased yields and substantial savings in utilities and raw material costs. For context, the key benefits achieved are:

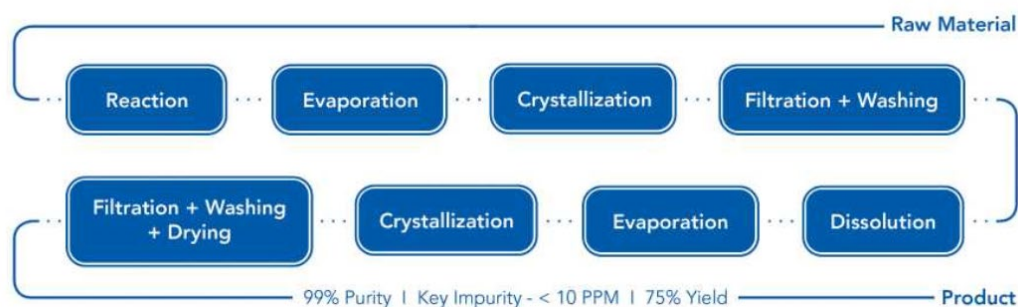
- 42 % reduction in raw material consumption
- 50 % decrease in wastewater generation
- 10 % increase in product yield
- 80 % reduction in power consumption
- 80 % footprint reduction compared to traditional batch plant

These results underscore the profound impact of continuous processing on efficiency, sustainability, and cost-effectiveness.

## Batch Process

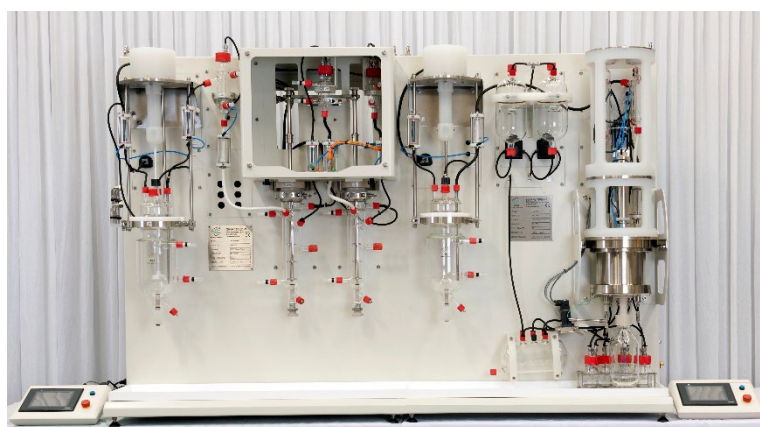
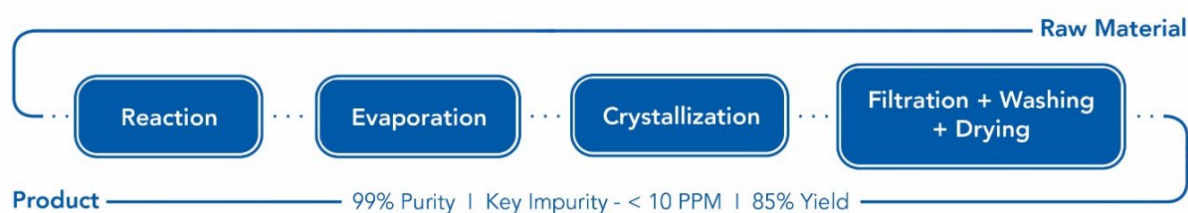
Historically, batch processing has been the foundation of operations in the chemical and pharmaceutical industries. Companies have invested in multi-story production facilities designed to accommodate traditional batch and gravity-driven processes. However, there is a growing shift toward continuous manufacturing methods, enabling businesses to reduce process steps, enhance yield, and optimize costs and waste management.

Let's take a closer look at the batch process utilized by our customer:



## Continuous Process Optimization

A comprehensive laboratory demonstration, followed by individual unit operation trials, was conducted for evaporation, crystallization, filtration, washing, and drying of the input material. The trial results demonstrated significant improvements in product quality and yield, attributable to technological enhancements. Notably, the process was optimized to eliminate the second-stage purification, reducing the overall process from 11 steps to just 6. This streamlined approach resulted in synergistic benefits, including lower operating and raw material costs, as well as increased product yield.



*Lab-Scale Continuous Crystallization and Filter-Drying*

## Assumptions and Variables

### Basic Information

To effectively present our case, we first establish key foundational data, all specific to the Gujarat region in India. The manufacturing facility produces 4 tons of dry product daily, operating around 300 days annually. The product's market price typically fluctuates around €6.18 per kilogram.

All cost estimates provided - including water, waste treatment, brine management, power, and other operational expenses - are derived from region-specific industry standards applicable to Gujarat. Currency conversions INR-EUR reflect the exchange rate of May 2025.

| Particular                | Assumption                                                                                                                               | Reasoning<br>(all data consider regionalization – Gujarat, India)                      |
|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Plant Capacity            | 4 Ton/day dry Product                                                                                                                    | Client requirement                                                                     |
| Number of Operating Days  | 300 days per year                                                                                                                        | Industry norms                                                                         |
| Yield Improvement         | 5%                                                                                                                                       | Actual Demonstrated ~9%                                                                |
| Raw Material Cost         | Batch - 2,74 EUR/kg of Product<br>Continuous - 2,62 EUR/kg of product<br>6,18 EUR/kg                                                     | Due to the elimination of the second stage, the solvent consumption was reduced by 50% |
| Product Selling price     | 0,02 EUR/kg of Product                                                                                                                   | Shared by Client as the lowest selling price                                           |
| Wastewater Treatment cost | 0,02 EUR/kg of Product                                                                                                                   | As per the industry standard, it varies from 0,02-0,04 EUR/kg of Product.              |
| Utility Cost              | Steam - 0,02 EUR/kg<br>Hot water - 0,025 EUR/kg<br>Cooling Water - 0,015 EUR/TOR<br>Chilled Water - 0,04 EUR/TOR<br>Brine - 0,13 EUR/TOR | The utility cost is considered from the Gujarat region and based on industry norm.     |
| Power Cost                | 0,08 EUR/kWh                                                                                                                             | Industry-standard                                                                      |
| Manpower Cost             | In charge - 412 EUR/month<br>Operator - 258 EUR/month<br>Labor - 155 EUR/month                                                           | As per industry standard                                                               |

## Economic Analysis & Process Optimization

### Raw Materials

By eliminating the second stage of purification, we significantly reduce the use of solvents during evaporation and crystallization processes. This optimization has led to a 42% reduction in raw material consumption per kilogram of product. Specifically, the batch process requires 8 kg of raw materials per kg of product, whereas the continuous process decreases this requirement to just 4 kg. The following table details the raw material norms per kilogram of product for the reference batch, highlighting this efficiency gain.

## Wastewater Treatment Costs

The 42% reduction in raw material usage also results in a 50% decrease in wastewater generation, thereby lowering treatment costs and minimizing environmental impact.

| Batch Process                                                          |      | Continuous Process |               |                    |
|------------------------------------------------------------------------|------|--------------------|---------------|--------------------|
| Kg of waste/kg of Product                                              |      |                    |               |                    |
| Aq. Waste                                                              | 2.43 | Client requirement |               |                    |
| Organic Waste                                                          | 4.34 | 2.48               |               |                    |
| Total Waste Generated                                                  | 6.77 | 3.36               |               |                    |
|                                                                        |      | Units              | Batch Process | Continuous Process |
| Aq. Waste generated per day                                            |      | kg/day             | 9717          | 3510               |
| Treatment Cost per kg (Range- 0,02-0,04 EUR/kg)                        |      | EUR/kg             | 0,02          | -                  |
| Treatment Cost EUR Per day                                             |      | EUR/day            | 200           | 72                 |
| Yearly Saving on water treatment cost                                  |      | EUR/year           | 59.726,00     | 21.625,00          |
| Yearly Saving on water treatment cost (Batch vs Continuous difference) |      | EUR/year           | 38.101,00     |                    |

## Utility Costs

The utility requirements for the batch process are inherently higher than those for the continuous process, primarily due to shorter processing times. However, heat integration offers a promising avenue to improve efficiency - by utilizing heat streams to preheat incoming feeds, overall utility consumption can be significantly reduced. Notably, in this process, eliminating the second stage of purification decreases utility usage by over 50%. Additionally, the solvent recovery load drops by 50%, collectively leading to an overall utility cost reduction of approximately 75%. This highlights the potential benefits of process optimization and heat recovery strategies in minimizing energy expenses.

## Power Consumption

The batch process is inherently slower, processing several cubic meters over extended periods - approximately 65 m<sup>3</sup> over 85 hours - resulting in higher power consumption. In this case, the total energy used was about 400 kWh, equating to roughly 1.2 kWh per cubic meter. Conversely, the continuous process handles smaller volumes - less than 1 m<sup>3</sup> - and completes processing in under 3 hours, which substantially lowers energy consumption. Moreover, removing the second stage of purification further enhances energy efficiency.

The table below summarizes the quantitative comparison between the two processes, illustrating the significant energy savings achievable through continuous operation and process simplification.

| Process Steps                 | Batch                 |                          |            | Continuous            |                          |            |
|-------------------------------|-----------------------|--------------------------|------------|-----------------------|--------------------------|------------|
|                               | Process<br>(Time, Hr) | Process<br>(Volume, Lit) | kW<br>(h)  | Process<br>(Time, Hr) | Process<br>(Volume, Lit) | kW<br>(h)  |
| Reaction                      | 17                    | 5176                     | 73         | 1                     | 50                       | 0.5        |
| Evaporation 1                 | 8.5                   | 5188                     | 37         | 0.5                   | 50                       | 0.5        |
| Antisolvent Crystallization 1 | 11                    | 6323                     | 58         | 0.5                   | 200                      | 2.0        |
| Filtration and Washing 1      | 8                     | -                        | 32         | 0.15                  | 5                        | 0.1        |
| Dissolution                   | 0.5                   | 5536                     | 2          | -                     | -                        | -          |
| Evaporation 2                 | 14                    | 5536                     | 65         | -                     | -                        | -          |
| Antisolvent Crystallization 2 | 12.5                  | 6148                     | 64         | -                     | -                        | -          |
| Filtration and Washing 2      | 4                     | -                        | 16         | -                     | -                        | -          |
| Dryer                         | 10                    | 6667                     | 56         | 0.1                   | 28                       | 0.3        |
| <b>Total</b>                  | <b>85.5</b>           | <b>6667</b>              | <b>403</b> | <b>2.25</b>           | <b>333</b>               | <b>3.3</b> |
| <b>Power Cost, EUR/kg</b>     | <b>0,0083</b>         |                          |            | <b>0,000072</b>       |                          |            |

## Benefits of Yield Improvement

The transition to a streamlined continuous process has significantly reduced the number of process steps from 11 to 6, leading to notable improvements in overall yield. Pilot-scale trials have demonstrated a yield increase of approximately 9.4%. However, for the purpose of conservative and reliable economic analysis, we are considering an achievable and proven yield enhancement of 5%.

## Batch Plant Capital Expenditure (CAPEX)

The CAPEX for the batch plant has been meticulously estimated by compiling a comprehensive list of required equipment. Equipment costs were determined through consultations with vendors and leveraging the expertise of the client's team. Additional costs associated with utility piping, electrical connections, and other supporting infrastructure are estimated as a percentage of the equipment costs. The following table provides detailed information on the equipment and associated costs for the batch plant.

| Particular                | Assumption                                                                                                                           | Reasoning<br>(all data consider regionalization – Gujarat, India)                      |
|---------------------------|--------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Plant Capacity            | 4 Ton/day dry Product                                                                                                                | Client requirement                                                                     |
| Number of Operating Days  | 300 days per year                                                                                                                    | Industry norms                                                                         |
| Yield Improvement         | 5%                                                                                                                                   | Actual Demonstrated ~9%                                                                |
| Raw Material Cost         | Batch- 2,74 EUR/kg of Product<br>Continuous- 2,62 EUR/kg of product<br>6,18 EUR/kg                                                   | Due to the elimination of the second stage, the solvent consumption was reduced by 50% |
| Product Selling price     | 0,02 EUR/kg of Product                                                                                                               | Shared by Client as the lowest selling price                                           |
| Wastewater Treatment cost | 0,02 EUR/kg of Product                                                                                                               | As per the industry standard, it varies from 0,02-0,04 EUR/kg of Product.              |
| Utility Cost              | Steam - 0,02 EUR/kg<br>Hot water- 0,025 EUR/kg<br>Cooling Water- 0,015 EUR/TOR<br>Chilled Water- 0,04 EUR/TOR<br>Brine- 0,13 EUR/TOR | The utility cost is considered from the Gujrat region and based on industry norm.      |
| Power Cost                | 0,08 EUR/kWh                                                                                                                         | Industry-standard                                                                      |
| Manpower Cost             | In charge- 412 EUR/month<br>Operator- 258 EUR/month<br>Labor - 155 EUR/month                                                         | As per industry standard                                                               |

Of the total project cost, 50% is allocated to civil, structural, and equipment expenses. For continuous plant configurations, the civil and structural costs are significantly lower, primarily because the overall footprint is reduced. Additionally, costs can be further decreased by eliminating the second stage of purification, streamlining the process and minimizing infrastructure requirements.

### Continuous Plant Capital Expenditure (CAPEX)

The CAPEX for the Continuous Plant encompasses costs associated with plant equipment and auxiliary components, which have been estimated based on the figures used for the Batch Plant CAPEX.

| SN                                | Description                                           | Cost (Cr)    | Remark                             |
|-----------------------------------|-------------------------------------------------------|--------------|------------------------------------|
| 1                                 | Civil & Structures                                    | 13.39        | As per Civil Area Estimation       |
| 2                                 | Facility & Clean Room                                 | 0.94         | 6% of Equipment Cost               |
| 3                                 | Process Equipment                                     | 15.45        | As per Equipment Cost Estimation   |
| 4                                 | Warehouse Equipment                                   | 0.46         | 3% of Equipment Cost               |
| 5                                 | HVAC                                                  | 1.50         | Estimated Cost                     |
| 6                                 | Process + Utility Piping & Mechanical Contractor cost | 6.18         | 40% of Equipment Cost              |
| 7                                 | Job Order                                             | 2.32         | 15% of Equipment Cost              |
| 8                                 | Electrical                                            | 3.14         | 20% of Equipment Cost              |
| 9                                 | Instrumentation & Control                             | 4.52         | 30% of Equipment Cost              |
| 10                                | FIRE & SAFETY                                         | 0.83         | 5% of Equipment Cost               |
| 11                                | Insulation and Painting                               | 1.16         | 7.5% of Equipment Cost             |
| 12                                | QC<br>(Instruments + Furniture's)                     | 4.50         | Separately Estimated Cost          |
| 13                                | IT & Furniture + SPARE                                | 0.50         | Estimated Cost                     |
| 14                                | Construction Management and Consultancy               | 0.60         | Estimated Cost                     |
| 15                                | Fright and Taxes                                      | 0.23         | 1.5% Considered on Equipment       |
| <b>CAPEX – Continuous Process</b> |                                                       | <b>55.71</b> | <b>Translates to 5 725 121 EUR</b> |

## CAPEX Comparison Between Batch and Continuous Processing

### Civil and Structural Cost

In batch processing, products are collected in batches, which typically require larger spatial footprint and handling capacity to accommodate the entire batch at once. Conversely, the Continuous Plant employs an automated, dedicated continuous packing system, significantly reducing the required space and minimizing the need for auxiliary accessories.

As reflected in the accompanying table, the civil and structural costs include the second-stage purification process. Omitting this stage reduces these costs by approximately 40%, offering potential savings.

Utility Plant Sizing and Cost Implications

The utility plant, comprising the steam boiler and brine plant, has been designed based on peak demand:

Brine Plant

- Batch process:** Peak brine load of approximately 39 tons of reagent (TOR)
- Continuous process:** Steady-state operation with a peak load of around 10 TOR, enabling CAPEX savings for the brine system.

Steam Boiler

- Batch process:** Peak load during evaporation processes estimated energy at 730 kW
- Continuous process:** Due to steady operation, the required boiler consumption is reduced to approximately 172 kW, leading to significant CAPEX reductions.

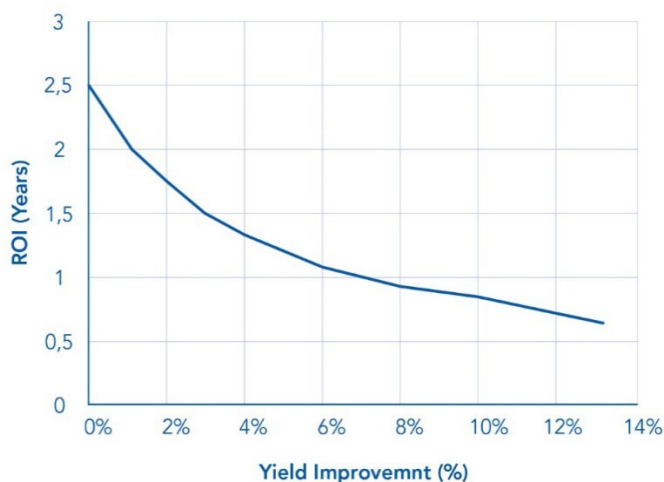
| Steam Utility                       | Batch             | Continuous |
|-------------------------------------|-------------------|------------|
| Total Water Evaporation, kg         | 3494              | 275        |
| Time, Hr                            | 6                 | 1          |
| Peak Load of evaporation, kg/hr     | 1165              | 275        |
| Latent Heat of Evaporation, kcal/kg | 540               | 540        |
| Peak Steam Load kcal/hr             | 628920            | 148500     |
| Boiler Capacity, kW                 | 730               | 172        |
| Boiler Capacity                     | 979               | 231        |
| Cost of Boiler, lakh                | 30                | 5          |
| Saving Steam Plant CAPEX            | 25.0 (25 691 EUR) |            |
| Total Saving on Utility CAPEX, Lakh | 57.1 (58 679 EUR) |            |

| Total CAPEX, Cr | Batch Plant        | Continuous Plant   |
|-----------------|--------------------|--------------------|
|                 | 55.7 (592 390 EUR) | 64.7 (664 258 EUR) |

Overall, by adopting a conservative approach and incorporating an appropriate safety margin, the estimated CAPEX for the Continuous Plant is approximately 17% higher than that of the Batch Plant.

# Economical Risk Analysis

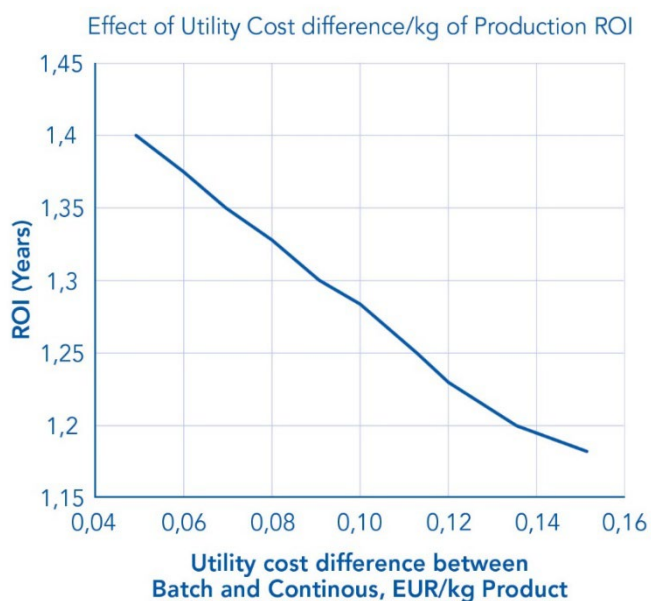
## Yield Performance



The continuous process has achieved a 10% yield enhancement at the laboratory scale. While the yield improvement during the reaction stage remains to be fully established, there is potential for an additional 2-3% increase through plant-scale optimization.

The impact of yield improvements has been analyzed across a range from 0% to 13%, providing insights into the associated economic benefits and risks.

## Utility Cost Analysis



The estimated utility cost for the Batch Plant is 0.17 EUR/kg of product. In contrast, due to the elimination of the second stage and a 50% reduction in evaporation load in the ML recovery, the utility cost for the Continuous Plant is reduced to approximately 0.045 EUR/kg of product. This results in a cost difference of about 0.125 EUR/kg.

The assumptions used in the utility calculations are consistent for both processes; however, individual process parameters may cause some variation in the actual figures. Nonetheless, this variation is unlikely to significantly impact the overall comparison.

For analytical purposes, considering utility costs within the range of 0.05 to 0.15 EUR/kg of product, the effect on ROI with a 5% yield improvement can be assessed. Given that the Continuous Plant consistently uses less utility than the Batch Plant - supporting the rationale behind this cost window - this analysis highlights the potential economic benefits of process optimization.

The analysis clearly indicates that yield has a greater impact on the economics than utility costs. However, the key takeaway is unmistakable: regardless of circumstances, the ROI remains well within a timeframe of less than 2.5 years, even with no yield improvement. In the worst-case scenario - assuming zero yield increase and utility benefits of only 0.05 EUR/kg - the ROI extends to just three years, which remains justifiable in the current market environment.

## Operating and Capital Cost Summary

The operating and capital cost components are consolidated in the table below to facilitate a comprehensive analysis.

| Operating Cost components                    | Unit                    | Batch            | Continuous       |
|----------------------------------------------|-------------------------|------------------|------------------|
| Raw Material Cost                            | EUR / kg Product        | 2,75             | 2,6              |
| Utility Cost (Including ML Recovery)         | EUR / kg Product        | 0,17             | 0,045            |
| Power Cost                                   | EUR / kg Product        | 0,008            | 0,0001           |
| Manpower Cost                                | EUR / kg Product        | 0,047            | 0,02             |
| <b>Total Operating Cost</b>                  | <b>EUR / kg Product</b> | <b>2,99</b>      | <b>2,60</b>      |
| Saving on Operating Cost/ kg of Product      | EUR / kg Product        | 0,28             |                  |
| Saving on Operating Cost/Year                | EUR / Year              | 351 334          |                  |
| Saving on Wastewater treatment cost/ Year    | EUR / Year              | 38 203           |                  |
| Revenue Generated by Yield improvement (5%)  | EUR / Year              | 372 000          |                  |
| <b>Total Saving Per Year</b>                 | <b>EUR / Year</b>       | <b>764 668</b>   |                  |
| <b>Capital Cost (CAPEX)</b>                  | <b>EUR</b>              | <b>5 786 681</b> | <b>6 716 684</b> |
| Differences in Batch & Continuous Investment | EUR                     | 927 935          |                  |
| % ROI                                        | %                       | 82%              |                  |
| <b>Payback Period</b>                        | <b>Yrs</b>              | <b>1.22</b>      |                  |

## Technical Risk Analysis

The manufacturing process has been extensively optimized in laboratory conditions, ensuring it is finely tuned to maximize both quality and quantity outputs. While the process appears straightforward, it requires precise control of operational parameters to consistently meet stringent target specifications. The primary technical challenges include maintaining impurity levels below 10 ppm, moisture content under 0.5%, and achieving the desired particle size distribution.

Milling emerges as the most critical and inefficient stage within this process. It consumes significant energy and generates heat, which introduces additional operational complexities such as temperature management. Despite these challenges, even a targeted 20% reduction in milling could lead to substantial cost savings, both in capital expenditures (CAPEX) and operational expenditures (OPEX).

## Conclusion

Continuous Process Technology has demonstrated significant advantages at the laboratory scale, including:

- 42% reduction in raw material consumption, enhancing sustainability and lowering the carbon footprint
- 50% decrease in waste generation, supporting solvent recovery and emphasizing prevention over treatment
- 80% reduction in power consumption, contributing to greener manufacturing practices
- Minimal batch-to-batch variability, aligning with the quality by design (QbD) principles to ensure consistent product quality
- Improved yield, with less resource utilization and better atom economy
- Reduced processing time and smaller processing volumes, inherently enhancing process safety by design (SbD)
- Potential to reduce the overall plant footprint by up to 80%
- Opportunities to decrease milling capacity by manipulating particle size during crystallization, further optimizing process efficiency

Given the strict specifications for impurity levels, moisture content, and particle size, traditional batch processes often require multiple purification steps, leading to inefficiencies. Continuous technology offers a compelling solution by streamlining these processes and delivering substantial benefits.

Economic risk assessments indicate that, within a broad operational window, the continuous process is economically viable, providing a favorable return on investment without compromising technological robustness.

Overall, continuous process technology presents a promising and sustainable alternative to conventional batch manufacturing, aligning with modern industry demands for efficiency, safety, and environmental responsibility.

