VOL. 02 · LIFECYCLE ECONOMICS

The Hidden Economics of Reliability

Quantifying the true cost of pressure vessel failure in reverse osmosis systems.

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Based on manufacturer-collected field data · Technical review: Impact Filtration Engineering

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> A surge of low-cost, short-lived FRP vessels has entered the market promising initial savings of 20–30%. Lifecycle analysis shows that each failure event can cost ten to twenty times the original purchase price.

1. Understanding cost of failure

A pressure-vessel failure rarely ends with a simple replacement. It triggers a chain of direct and indirect costs. Grouping them makes the total auditable rather than asserted — each category below can be checked independently against a plant's own maintenance records.

COMPOSITION OF A SINGLE FAILURE EVENT *

CATEGORY	DESCRIPTION	TYPICAL RANGE (USD)
A. Replacement materials	New vessel, fittings, seals	600 – 1,200
B. Emergency labor & logistics	Technicians, overtime, cranes, transport	1,000 – 3,000
C. Downtime / lost production	Plant or skid shutdown; lost water output	5,000 – 15,000+
D. Collateral damage & inspection	Membrane damage, cleanup, post-failure testing	500 – 2,000
Sum of midpoints	**The four ranges taken at midpoint**	**14,150**
Figure used	**Retained throughout — 92% of the midpoint sum**	**≈ 13,000**

FIGURE 1

Cost components of a single vessel failure. Even when one vessel fails in a multi-vessel array, the entire skid must be depressurized, drained and isolated — which is why downtime dominates the total.

TIER 3 · OPERATOR-SUPPLIED AND CASE-STUDY DATA · INDEX ADJUSTMENT TIER 2

* **Cost basis and vintage.** The dollar ranges above come from desalination operator data for the MENA region, **2015–2022**, and from undated engineering case studies in India, China and the GCC. AWWA Research Foundation (2009) is cited for a *ratio* — emergency maintenance of composite pressure components running 3–5× the base component price — and not for any dollar amount. A ratio carries no price vintage. **Figures are stated in source-year dollars and are not inflation-adjusted.**

Because downtime is the largest single component, at roughly 71% of the four components summed at their midpoints, the effective vintage of this basket is governed by the 2015–2022 operator window rather than by any earlier date. Indexing with CPI-U (US city average, all items; US Bureau of Labor Statistics), 336.940 in September 2026:

From the start of the window. 2015 annual average 237.017 — a factor of **1.42**, putting the basket near **$18,500** in 2026 dollars. This is the largest adjustment the window supports.

From its midpoint. 2018 annual average 251.107 — a factor of **1.34**, or about **$17,400**.

The analysis retains $13,000 throughout. On either basis the figure used here sits below the indexed range, so it is a floor rather than an estimate — which is the point: the conclusions do not depend on which year a reader indexes from.

2. Source and credibility of the estimate

The $13,000 figure used throughout this analysis is a conservative midpoint, not a worst case. It is corroborated by four independent reference points:

- **AWWA Research Foundation (2009)** — emergency maintenance for composite pressure components typically costs 3–5× the base component price.
- **Desalination plant operator data, MENA region (2015–2022)** — average downtime loss of $7,000–$15,000 per vessel event, depending on throughput and water tariff.
- **Engineering case studies (India, China, GCC)** — full vessel replacement with associated logistics averaged $10,000–$20,000.
- **ISO 15686-5 and ASTM D2992** — both emphasize lifecycle cost and design-basis validation as best practice for asset reliability.

$13,000 therefore represents a defendable mid-range global figure that avoids exaggeration while illustrating the economic consequence of premature failure. Readers modeling their own plant should substitute their own tariff and labor rates — Figure 2 allows exactly that.

One caution on vintage. None of these figures are inflation-adjusted. The dollar components date from 2015–2022; the 2009 reference supplies a ratio rather than a price, and a ratio does not inflate. Indexing the basket with CPI-U from the start of that window gives a factor of 1.42 (about **$18,500** in 2026 dollars), and from its midpoint 1.34 (about **$17,400**). The analysis keeps the lower number on purpose. A reader who holds that $13,000 is too low is agreeing with the direction of the argument rather than disputing it.

3. Lifecycle cost modeling

Applying standard Life-Cycle Cost Analysis methodology over ten years, with failure events for the price-optimized vessel at years 3, 6 and 9:

TEN-YEAR LIFECYCLE COST COMPARISON *

PARAMETER	INTEGRITY-GRADE	PRICE-OPTIMIZED
Purchase (CapEx)	$1,000	$700
Annual OpEx	$100	$120
Failure events	None	Years 3, 6, 9
Cost per failure	—	$13,000
Undiscounted total (10 yrs)	$2,000	$40,900
NPV @ 8%	**$1,671**	**$26,520**

FIGURE 2A

Even after discounting to present value, the price-optimized vessel is approximately **15.9×** more expensive across its service life. The apparent procurement saving of $300 per unit becomes the largest cost on the line.

TIER 3 · MODELED FROM TIER 3 COST INPUTS · ISO 15686-5 METHOD

* **Unit prices are illustrative.** $1,000 and $700 express the *ratio* between grades at a representative scale; they are not quoted market prices and will not match any particular tender. The failure cost carries the vintage noted in Figure 1. What the comparison demonstrates is the shape of the outcome, not the price of a vessel.

The table above fixes one scenario. The model below lets you vary it — plant scale, time horizon, failure rate, and the four components of the incident cost from Figure 1. The crossover year is where integrity-grade becomes the cheaper path.

INTERACTIVE MODEL — LIFECYCLE COST CROSSOVER

UNIT COST ($)

INTEGRITY-GRADE	PRICE-OPTIMIZED
1250	850

ASSET SCALE (VESSELS) **100**

TIME HORIZON (YEARS) **10**

PEAK FAILURE RATE **10%**

+ INCIDENT COST COMPOSITION

REPLACEMENT WARRANTY

Models vendor replacement of vessel material cost only. Labor, downtime and collateral damage remain with the operator.

RISK EXPOSURE — PRICE-OPTIMIZED

$744K

FAILURE COST OVER HORIZON

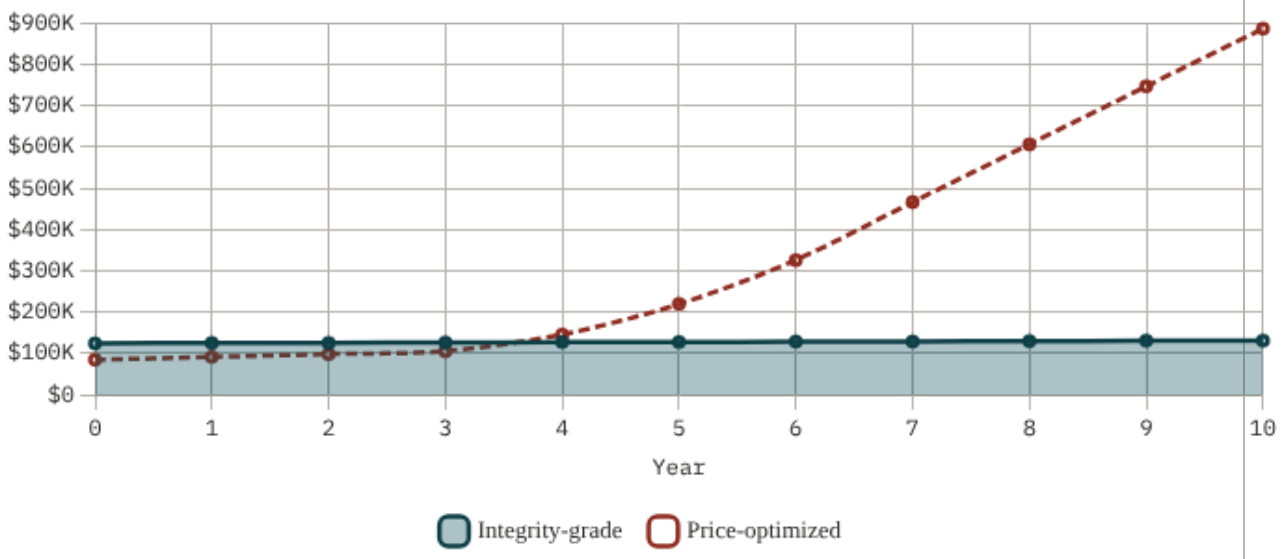
CUMULATIVE DIFFERENCE

$755K

INTEGRITY-GRADE ADVANTAGE

CUMULATIVE COST TREND

TREND GAP



+ VIEW CHART DATA AS A TABLE

FIGURE 2B

Illustrative model. Directional, not decision-grade. Failure incidence uses a two-phase assumption: 0.5% baseline in years 1–3, then a non-linear rise from year 4 representing structural matrix degradation. Losses are modeled as expected values, not worst cases. The decision-grade model — REM | The Crossover — is available through Sales.

TIER 3 · PROPRIETARY OPERATIONAL DATA — FAILURE-RATE ASSUMPTIONS

4. Financial interpretation

For financiers and investors, the implications are straightforward:

- **Predictable cash flow** — engineered vessels stabilize O&M budgets and reduce risk premiums.
- **Asset valuation** — plants equipped with long-life vessels show higher residual value and lower maintenance reserves.
- **Insurance and warranty** — demonstrated design integrity aligns with insurer expectations for reduced liability exposure.
- **ESG** — longer service life reduces waste generation and the carbon footprint of repeated replacement.

A vessel designed for reliability transforms a consumable component into a long-term capital asset. That reframing is examined in full in Vol. 03 <https://impactfiltration.com/insights/when-a-commodity-product-is-not-a-commodity/>.

5. Broader industry alignment

Global engineering bodies increasingly require lifecycle documentation for capital equipment. **ISO 55000** encourages total-cost-of-ownership-based replacement strategies. **FIDIC and World Bank procurement guidelines** mandate lifecycle cost submissions for high-value infrastructure. Major EPC contractors now evaluate membrane-housing vendors on verified fatigue data and cost-of-failure metrics rather than lowest bid.

High-reliability vessels are not a premium option. They are a financially prudent standard.

Conclusion

The apparent savings of low-cost FRP pressure vessels are an illusion. Once downtime, labor and lost production are factored in, each failure erodes profit and investor confidence. Independent lifecycle modeling and field evidence consistently confirm that quality engineering minimizes financial risk.

> ***Pay once for reliability — or pay repeatedly for recovery.***

References

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3. ISO 15686-5. *Buildings and Constructed Assets — Service Life Planning — Part 5: Life-Cycle Costing*.
4. ISO 55000. *Asset Management — Overview, Principles and Terminology*.
5. Regional desalination operator reports, MENA region, 2015–2022. Aggregated operator-supplied downtime data.
6. US Bureau of Labor Statistics. *Consumer Price Index for All Urban Consumers (CPI-U), US city average, all items*. 2009 annual average 214.537; September 2026 336.940.

7. US Bureau of Labor Statistics. *Consumer Price Index, Water and Sewer and Trash Collection Services, US city average* (series CUUROOOOSEHG). Used for the downtime component of the vintage reference in Figure 1.

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