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Technology with the Environment in Mind

Novel Wastewater Reclamation Technology Meets Environmental and Business Challenges

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ABSTRACT

In the relentless pursuit of Moore's Law, Intel's Technology Development cycle results in a new semiconductor production process every two years. As this continuous cycle of new products moves from conception to market, so do the innovative environmental solutions designed to meet Intel's philosophy of environmental excellence. Intel's success in design-for-environment (DFE) is widely recognized. In 2007 Intel was rated the top U.S. technology company to be named to the Dow Jones Sustainability Index—for the seventh straight year. In normal process technology development cycles, Intel's environmental systems are developed in parallel with the semiconductor manufacturing process. However, Intel is a global company and this proactive process sometimes needs adjusting to accommodate unique differences in local conditions.

Such a situation occurred recently for a new Intel High-Volume Manufacturing (HVM) facility that was under construction in an arid region. The technology development team faced a triple challenge of finding a technology solution that would meet water conservation needs, new environmental standards, and a compressed project schedule. The project site was being required to treat the entire wastewater stream of both new and existing factories to achieve a very high level of wastewater effluent quality and to meet water reuse and conservation priorities of the local authorities. Meeting the schedule while designing and implementing a system capable of achieving effluent quality targets that would also maximize water reuse became a paramount task, since the business permit for operating the Fab would not be issued without this infrastructure. With only half of the normal development time available and no prior Intel experience with the proposed wastewater treatment technology, a task force was formed from multiple

business groups to achieve successful completion of the project.

In this paper we focus on the following aspects of the aforementioned situation:

1. How the team incorporated risk-taking with other Intel best-known-methods to address both schedule and technology challenges.
2. The intensive technical study that resulted in the definition and optimization of the technology.
3. Value Engineering that resulted in design and construction of this system at costs normally associated with systems that are an order-of-magnitude smaller.
4. Creating greater water recycle opportunities by treating wastewater to such high standards.
5. The additional benefits of being able to treat other waste streams that are currently segregated.
6. The future challenges and opportunities associated with completion of this project.

INTRODUCTION

Intel announced plans to construct a new manufacturing facility emphasizing an ambitious schedule for construction. As with all technology-based manufacturing scenarios, time-to-market was paramount, and even small delays could affect the technology's financial success.

Seamless technology transfer from development to manufacturing is a trademark of Intel. Being proactive in identifying areas of risk and resolving roadblocks has allowed Intel to extend Moore's Law for four decades. The process of developing technology at a dedicated site, then copying it (using the Intel *Copy Exactly* process) during transfer to other manufacturing sites, has allowed

Intel to be a truly virtual factory, resulting in multiple factories worldwide producing identical products with standardized processes. This philosophy also applies to the design of environmental systems and promotes proliferation of high environmental performance including water conservation.

In normal product development cycles, Intel’s environmental engineers are allowed up to four years to identify problems and implement solutions. To meet future regulatory requirements and Intel’s global environmental standards, process environmental goals are developed well in advance of the technology.

Environmental requirements vary due to differences in geography, population density, industrial infrastructure, local regulations, and global initiatives. Despite these differences, Intel proliferates environmentally consistent and compliant technology worldwide, designed to meet requirements for the most sensitive or restrictive site. This approach allows flexible business expansion at any site with assurance of environmental compliance. When this process identifies a need for higher environmental performance, a technology selection process is followed to ensure the environmental systems match the technology roadmap. A simplified process for technology selection is outlined in Figure 1.

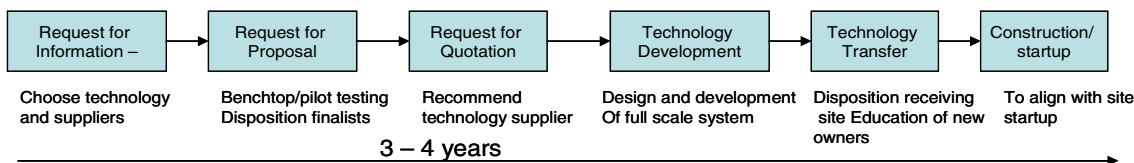


Figure 1: Technology selection process—steps normally do not overlap

This process does not easily accommodate unique site-specific conditions separate from the manufacturing process. Such a constraint occurred in this project when an unexpected change in the environmental requirements threatened the start-up date of the plant. In this case the construction schedule for the semiconductor plant outpaced the schedule for constructing the local municipal wastewater infrastructure. To avoid project delays, Intel developed its own solution for wastewater treatment and conservation. This coincided with the efforts of the local authorities to adopt more stringent wastewater quality standards intended to increase wastewater reclamation rates.

The new performance guidelines mandated use of effluent for unrestricted irrigation. Every drop of water discharged from the plant would ultimately be reused, either internally (by the plant) or externally. This means all water not evaporated and not used by building occupants could potentially be reused. Table 1 outlines these wastewater quality standards.

Table 1: Effluent quality requirements

Parameter	Quality standards for irrigation (mg/l)
COD	100
BOD	10
TSS	10
Ammonia	20
Total nitrogen	25

At this point, implementing technology selection, designing, and building an onsite treatment plant became a critical path for the startup of the new plant. Figure 2 shows the longer schedule for the municipal system compared with the schedule necessary for the onsite option.

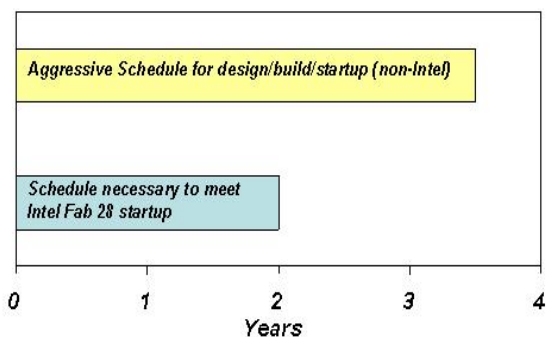


Figure 2: Technology implementation schedule

THE PROCESS

In contrast to the normal development process, the technology development effort would have to be modified and compressed by half to successfully meet the schedule.

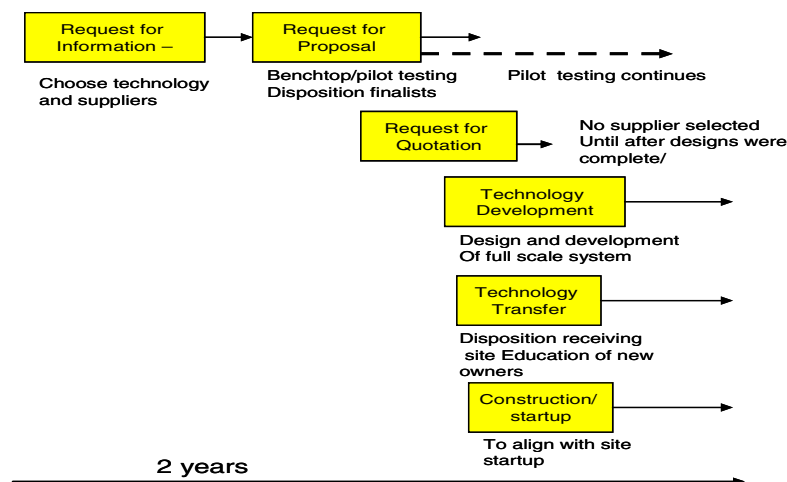


Figure 3: Modified selection process

Figure 3 illustrates the technology selection process that was used for this project. In the following section we review the parallel activities and the risk-taking decisions that drove this process.

Request-for-Information

By engaging in the parallel activities outlined above, the task force was able to quickly resolve many issues. The purpose of the Request-for-Information phase was to gather as much information as possible about the technologies available to treat Intel’s wastewater. One of

The site team moved into action and partnered with the development groups responsible for transferring the new technology to this project. This taskforce was a critical part of bringing in the technology. Engineers across Intel were chosen both for their expertise and availability. Wastewater experts, construction experts, environmental professionals, analytical/laboratory staff, commodities experts, project managers, and other support groups participated in this task force. The team’s mission was simple: enable the site to meet both the business permit requirements and the construction schedule. The taskforce first obtained top management support for this accelerated process to validate the business urgency and help ensure success.

SCHEDULE RULES

One of the first decisions made by the team was to define the project priorities. In this case, all parties agreed that *Schedule* was the primary driver, followed by performance, and finally budget. This hierarchy was extremely important in defining the team’s business practices.

the key tenets that the project team used during this phase was redundancy. Because the schedule would be compressed, and the time to test multiple iterations of technology was minimal, it was important to obtain the information as quickly as possible. Multiple third-party consultants and extensive literature surveys were used, in addition to Intel’s experts, to ensure that all technology options were being explored. One of the first activities was to characterize semiconductor wastewater for the constituents of concern. The outcome showed that in addition to the process wastewater containing organics

and nitrogen, the wastewater from one of the Fab functional areas and the slurry solids from another area could require pretreatment. Figure 4 outlines the potential treatment and segregation streams.

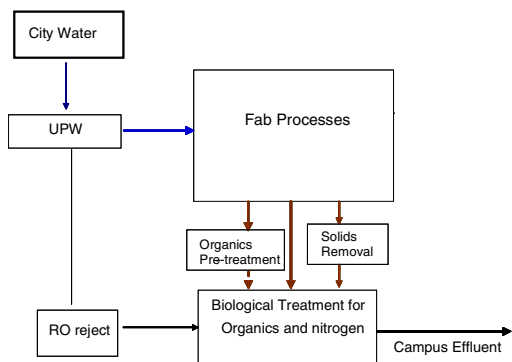


Figure 4: Segregation and pretreatment options for semiconductor wastewater

The next phase was to narrow down the options for treatment. Because of the restrictive solids limitations, only advanced biological treatment options were chosen. After additional analyses with vendors, only one technology seemed feasible to meet required timelines: the membrane bioreactor (MBR). See Figure 5 for a schematic of this MBR technology [8].

Request for Proposal/Request for Quotation

With viable MBR technologies available from two suppliers, the taskforce made the “at risk” decision to

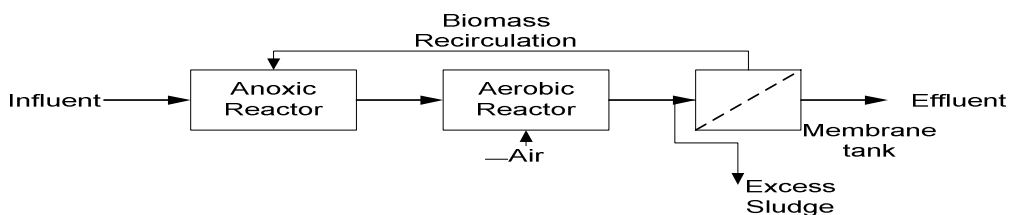


Figure 5: Membrane Bioreactor (MBR) process flow

As the vendors initiated design, both pilot systems confirmed that the MBR technology could treat Intel wastewater to the required effluent quality. One key barrier to validating the technology was that Intel’s chemical “recipes” were still being developed. To reduce risk, one pilot system was left running throughout the technology development activities. An additional benefit from leaving one pilot system in operation would be to optimize design parameters and test further technology applications.

continue through pilot testing and design with both suppliers. With two options being developed, the development team intended to again use redundancy to compensate for the compressed schedule. This initial cost in both support (manpower) and rental fees was appreciable, but it allowed the team to gain valuable insight into the two suppliers’ true capabilities regarding support, technical ability, operational needs, performance, and product quality. At the same time, Intel chose to operate each pilot system with “in-house” staff to ensure unbiased results while also minimizing operational costs. Part of qualifying the two systems involved placing analytical capability “in house”, resulting in rapid turnaround of analytical results for wastewater samples. This allowed us to quickly fine-tune and respond to process excursions thereby gaining significant cost savings while enabling development of operating procedures for full-scale system implementation.

As the pilot plants were being assembled and shipped, the taskforce realized that the scheduled startup would be delayed if the major milestones outlined in Figure 3 weren’t reached in parallel. Intel then asked both MBR technology suppliers to initiate designs even before feasibility testing and vendor selection was complete. In normal cycles, feasibility is confirmed, quotations are solicited, a vendor is chosen, and only then is design initiated. This new process would prove to have several benefits. In addition to providing competition, this allowed the vendors to supply accurate and quality bids that would be incomplete without the knowledge of the design details.

Request for Quotation (RFQ)

This phase of technology selection was another highlight for this team. With feasibility testing complete, and design proceeding, the task force was confident in the ability of each vendor to supply accurate bids. Each vendor was graded on technology development capabilities, initial design, bid preparation, and construction competence.

It should be noted that receipt of bids was a key milestone in this project. This marks the transfer of project

ownership from the Technology Development Group to the Project Team.

The supplier evaluation was performed by both the technology development task force and the project construction team. In addition, Intel's third-party experts were asked to review the "MBR Technology" scoring, to ensure accuracy, and to provide the critical second opinion. When the evaluation was complete, the supplier was chosen and announced. With the design work nearly complete at the time of supplier selection, the project moved quickly into construction. However, the Technology Development phase (including the pilot) continued to present new challenges that constantly altered the design and operations in the coming months.

Technology Development

At the time the contract was awarded to the vendor, the technology development task force had been working for nine months, and a pilot system had been running for six months. However, at this time, only feasibility had been proven, and there were still many unanswered questions. Among these was the ability of the chosen MBR technology to remove certain organics and solids without pretreatment.

At this point, technology development, transfer, and construction became concurrent activities. Due to the complexity of this process and the continually changing effluent composition, technology development was viewed as the key to success. Analyzing and characterizing the multiple organic compounds, modeling the outputs, setting up Design of Experiments for the pilot, developing analytical capabilities, and many other activities were keystones of the technology development process.

Unlike most projects (where design is not final), the construction team was already preparing the site for building even before the supplier selection was finalized. Late-breaking technology decisions would be incorporated into the design real-time and adjustments made accordingly. To offset the expected change orders, the project team initiated an aggressive Value Engineering effort to minimize cost while maintaining all the necessary treatment requirements.

Changes to the full-scale system based on technology development outcomes are expected to continue throughout the construction and start-up phase.

MEMBRANE BIOREACTOR PERFORMANCE AND APPLICATIONS TO FURTHER WATER REUSE

Background

The semiconductor industry uses ultrapure water (UPW) to rinse impurities from the wafer surface. Once contaminated with dissolved and suspended solids, organic and ammonia nitrogen, and multiple organic compounds, most semiconductor manufacturers discharge their wastewater offsite to municipal treatment plants, where these contaminants are removed. Although some companies reclaim some of this water for facilities applications (e.g., scrubbers, cooling towers), most UPW is treated as a "once-through" opportunity, limiting possibilities for water conservation.

MBR technology is not new and has been proven in many applications for organic, suspended solids and nitrogen removal. The technology development team quickly noted that effluent from the pilot plant was producing water comparable in quality to city water and might be suitable to replace city water in the UPW system feed. This was consistent with the data in literature that indicated that the MBR was quickly gaining recognition as the most effective process for treatment of industrial wastewater. In many cases, the MBR has been proven to produce very high-quality effluent suitable for almost unrestricted recycling. In fact, some U.S. states (e.g., Oregon) are currently revising their rules for reclaimed water to classify MBR effluent as Level IV reclaimed water, the highest purity classification available [13].

Semiconductor Wastewater Characteristics

Data in the literature indicates that the typical industrial effluent from semiconductor plants has the following characteristics, listed in Table 2.

Table 2: Characteristics of semiconductor plant effluents

Parameter	Concentration	Reference
pH	6-9	[14]
Biological oxygen demand (BOD)	50-200 mg/L	[14], [6]
Chemical oxygen demand (COD)	200-300 mg/L	[15]
Nitrogen	10-70 mg/L	[14]
Suspended solids (SS)	20-50 mg/L	[14], [15]

Of the organic compounds typically used in semiconductor manufacturing, the compound used in the new plant had been reported to pose a problem for biological treatment. Although the organic compound can be biodegraded by certain strains of bacteria [7, 10] its biodegradation in conventional wastewater treatment systems was reported to be slow and incomplete [5, 11]. For this reason, both total organics degradation and the removal efficiency for this particular organic compound were evaluated.

Organic matter (shown as COD and BOD in Table 2) has been demonstrated to severely reduce the performance of RO membranes [3]. Therefore, effective removal of organics is also critical if treated effluent is to be reused.

MBR Pilot Operation

The MBR pilot was operated at an Intel Technology Development location for 14 months. The pilot system treated 1.8 gpm of the combined effluent from the factory and consisted of aerobic and anoxic biological reactors followed by the membrane module. Pretreatment was accomplished using an ultrafilter (UF) module utilizing hollow-fiber membranes operated under vacuum. Additionally, 100 mg/L of the problematic organic compounds were added to the waste stream over the entire period of operation to simulate worst-case conditions.

Analytical

The pilot was equipped with an on-line system for measuring turbidity in the final effluent. Suspended solids, oxidizable organics, and nitrogen (ammonia nitrogen, organic nitrogen, nitrates, and nitrites) were measured in both waste stream and treated effluent. In addition, Total Organic Carbon (TOC) was periodically measured using a TOC analyzer. Tests were performed in accordance with Standard Methods [1]. For the compound in question, concentration in the treated effluent was measured by a vendor using a proprietary method.

RESULTS

Treated Effluent Quality

Biological Oxygen Demand (BOD) tests are typically used to measure organic matter content in treated wastewater. However, these parameters cannot be directly translated into a concentration of organics if the exact chemical composition is not known. For this reason, TOC measurements were also conducted.

Analyses of data from the pilot operations indicated stable and effective removal of nitrogen compounds, organic matter, and suspended solids to levels lower than required (Table 1). In addition to nearly complete removal of organics and TKN, complete biodegradation of the other organic compound was confirmed by direct measurements. In all samples the concentration was below the detection limit of 4 mg/L.

Several projects have recently reported the feasibility of reuse of biologically treated municipal wastewater. Most of the systems included microfiltration (MF) followed by RO [12, 9]. A range of treated wastewater parameters from the literature, for which MF/RO treatment was successfully implemented, is shown in Table 3.

Table 3: Treated wastewater quality parameters

Parameter	Values reported in literature	Values observed in this study
BOD, mg/L	2-12	Below 0.5
TOC, mg/L	11-40	1.5-8
Turbidity, NTU	2.3-33	Less than 0.2
TDS, mg/L	490-1200	NA
Conductivity, μ S/cm	820-2000	NA
Organic N, mg/L	1.4-9.7	Less than 0.4

MF pretreatment was needed to remove suspended solids that were present in the treated municipal wastewater, as evidenced by the effluent turbidity. Data in Table 3 suggest that combined effluent of a semiconductor Fab can be treated to achieve a quality exceeding that reported in other successful water reuse projects. Low turbidity values observed in this study are due to the fact that MBR utilizes UF for biomass separation, and that effectively removes all suspended solids and potentially eliminates the need for RO pretreatment. In fact, RO was successfully applied directly to the MBR effluent in several previous studies [2, 4].

Cost Considerations

Water reuse concepts ranging from irrigation to UPW recycle as described in this paper can be implemented at competitive cost, providing both monetary and resource conservation benefits. The feasibility of this approach can only be determined on a case-by-case basis. The following considerations must be taken into account in the cost/benefits analysis:

Costs

- Capital cost of the MBR.
- MBR operating cost.
- UPW system upgrade if the existing system does not have the capacity to operate at reduced recovery rate.
- Higher volume of RO reject.

Benefits

- Environmental protection and water conservation.
- Greatly reduced dependency on local infrastructure.
- Reduced water bill and wastewater treatment fee.
- Reduced use of RO pretreatment systems, since MBR effluent can be directly fed to RO.
- In some cases, MBR may eliminate the need for certain waste treatment systems (e.g., ammonia, solvents, waste neutralization), thus fully or partially off-setting the capital cost.
- Reduced dependence on availability and quality of local water supply.

CONCLUSION

In summary, environmental challenges that threatened to delay the startup of a new semiconductor facility drove the technology development team to define a new technology selection process as well as a new treatment technology. The new technology application met all environmental requirements and will enable reuse of all factory wastewater. The team had a clear charter that prioritized schedule, thus enabling informed risk-taking to speed development, and redundancy to minimize risk.

It has been proved that MBR can adequately treat semiconductor wastewater to the standards proposed by local authorities to enable unrestricted reuse of the wastewater for irrigation. In addition to implementing the technology to enable startup, many side benefits are possible as a result of the high water quality that will be discharged from MBR applications. In arid geographies where Intel operates several facilities, the unlimited reuse opportunities for water are even more important.

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