Apply Process Integration to Environmental Impact Assessment

Mahmoud M. El-Halwagi
Texas A&M Univ.

Eva M. Lovelady
Mustang Engineering

Ahmed Abdel-Wahab
Patrick Linke
Texas A&M Univ. at Qatar

Hassan E. Alfadala
Qatari Diar

This approach provides valuable insights early in the design process and systematizes the design effort, while reconciling process objectives with environmental constraints.

Environmental impact assessment (EIA) is a procedure for determining, assessing and mitigating a proposed project's biological, physical, chemical, economic and social consequences on the environment. When the EIA addresses broad goals and focuses on policies, plans and programs for an area, a region or an industrial sector, the effort is known as strategic environmental assessment (SEA) *(1)*.

An environmental impact assessment estimates a project's environmental effects in an effort to prevent adverse impacts before major resource commitments are made *(2)*. This early incorporation of environmental issues looks beyond environmental regulations and considers interactions with neighboring systems and spatial/temporal tracking of discharges. It is important in the selection of design alternatives — once potential environmental problems are identified, the design can be altered or a new design alternative generated to address the concerns raised during the analysis.

Recognizing the need for EIAs, countries around the world have enacted regulations covering their nature, scope and format. Although the specific implementation procedures may differ from one country to another, there are common themes for a conventional EIA and for its documentation (referred to as the environmental impact statement, or EIS).

The EIA procedure

Typically, an EIA involves some variation of the following steps (Figure 1):

1. *Describe the project*. Prepare an overview of the nature and objectives of the proposed project. The description should discuss the main features of the production process, the selected site, and a basic characterization of the interactions of the process' environmental and social components.

2. *Conduct preliminary screening*. Determine whether an EIA is required for the project, and/or any of its parts.

3. *Perform scoping*. Conduct a top-level analysis to identify the primary matters to be included in the EIA and the extent to which these matters should be addressed.

4. *Describe the baseline environment*. In order to track any environmental impacts of the proposed project, it is important to gather and document data (*e.g.,* physical, biological, economic, social) on the existing state of the environment, including the interacting components (*e.g.,* industrial, residential, etc.) and planned developments.

5. *Generate alternatives and process descriptions*. This step involves the generation and characterization of potential technologies and solutions for the project. For each alternative, develop a process description that provides sufficient details about the process (*e.g.,* block flow diagrams, basic mass and energy balances, needed labor,

construction phases, site information, etc.). Assumptions, design bases, and data gaps and uncertainties should be documented.

6. *Identify impacts*. This is a top-level (usually qualitative) analysis of the impacts of project activities, with emphasis on determining which ones warrant a more-detailed study.

7. *Predict and evaluate impacts*. Assess — quantitatively whenever possible — the consequences of planned activities on the environment. Describe both positive and negative consequences in terms of magnitude, significance, reversibility, frequency of occurrence, period of occurrence, and nature of the impact.

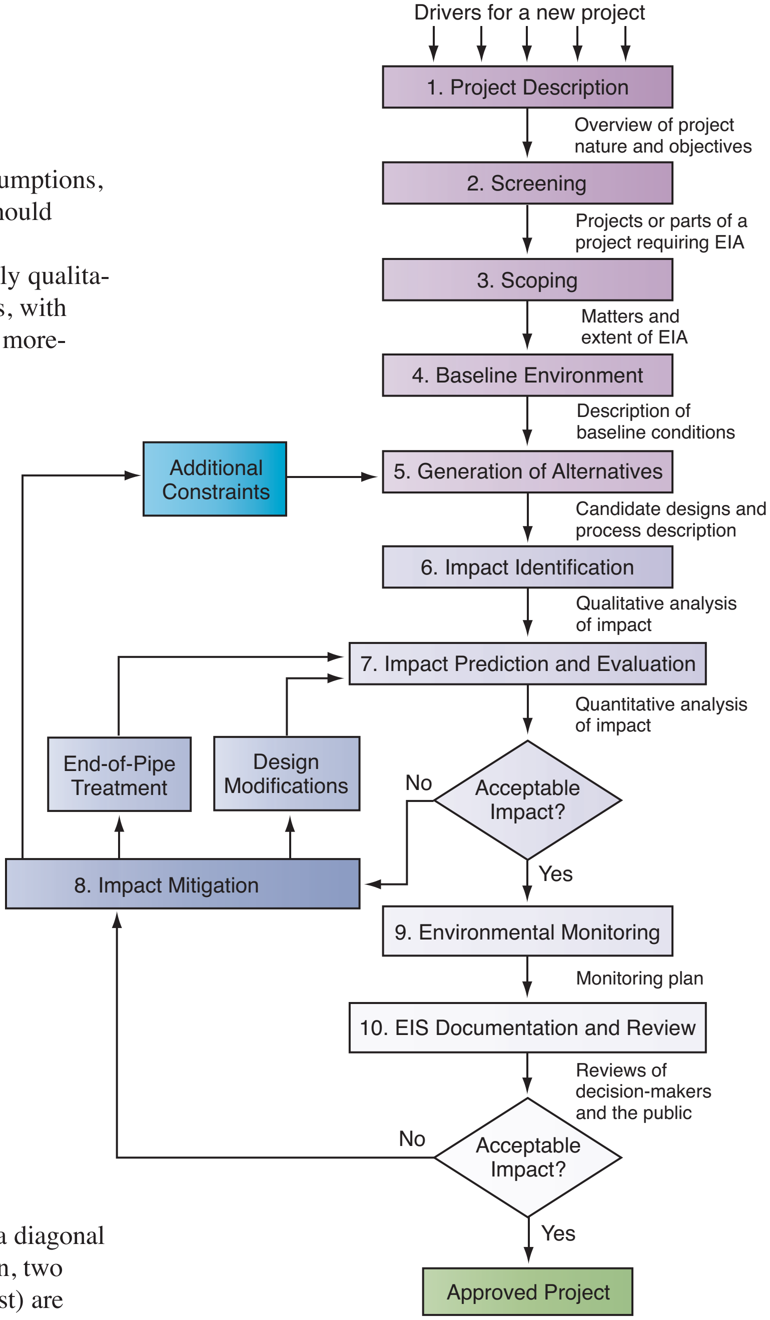
Several methods may be used to predict and evaluate the impacts, such as checklists, matrix methods, and mathematical models.

Checklist methods solicit information using forms and guiding questions. These techniques are simple and easy to use.

Matrix methods provide a two-dimensional approach for assessing the type and extent of environmental impacts. An example is the Leopold matrix *(3),* which lists project activities along one axis (*e.g.,* raw materials consumption, processing units, water supply, energy supply, construction work, atmospheric emissions, liquid effluents, solid wastes) versus segments of the environment along the other axis (*e.g.,* air, water, soil, fauna, flora, population, economy). Whenever there is a significant physical, biological or social interaction between a column and a row, a diagonal line is drawn across the corresponding cell. Then, two numbers (on a scale of 1 = lowest to 10 = highest) are entered above and below the line, designating, respectively, the magnitude and the importance of the interaction.

Mathematical modeling provides a quantitative evaluation of the spatial and temporal impacts of the environmental phenomena of interest. Modeling may be mechanistic, semi-empirical or empirical. Examples include air-dispersion and water-quality models *(4–6).*

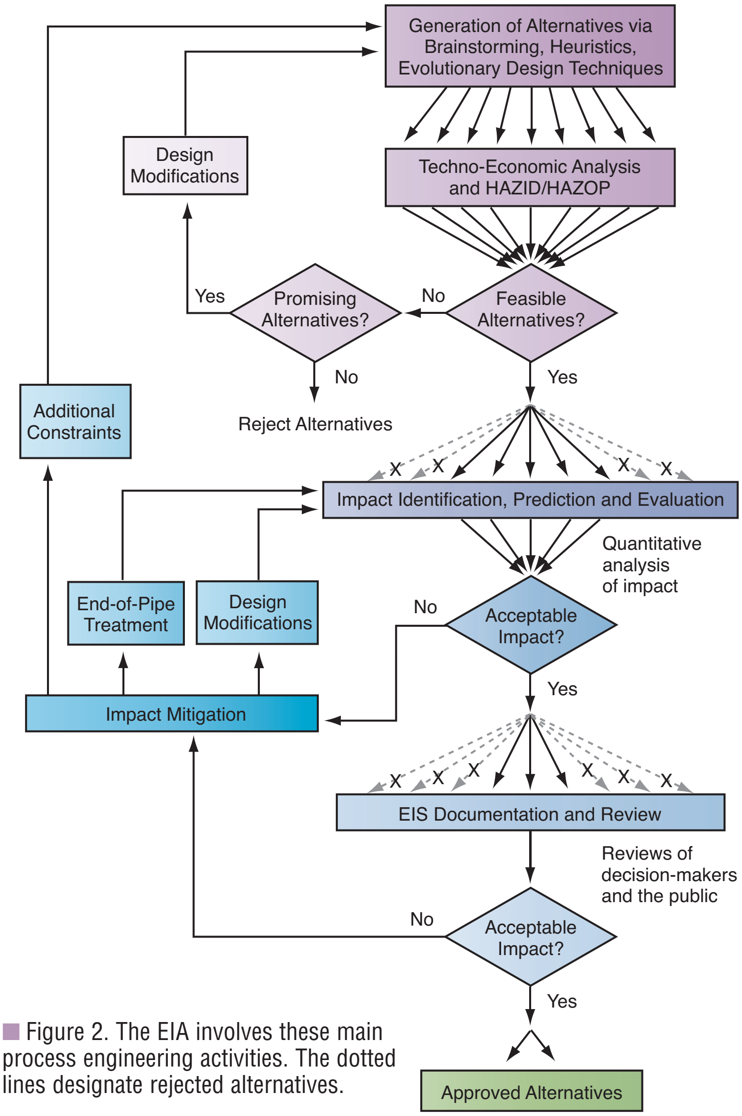
8. *Identify ways to mitigate impacts*. Based on the impact prediction and evaluation step, determine the magnitude and importance of the expected environmental consequences. For all those with negative repercussions, measures to eliminate the problems or abate them to an acceptable level must be developed. Mitigation approaches include design and operating modifications, addition of waste-treatment systems, and consideration of other process or technology alternatives.



■ Figure 1. An environmental impact assessment typically involves these steps.

In addition to assessing the environmental impacts of the mitigating solutions, their technical and economic performance must also be evaluated to ensure feasible and realistic implementation. If no viable solution is found, the proposed project is stopped. Therefore, it is necessary to employ effective and efficient process-engineering methods at this stage.

9. *Develop an environmental monitoring plan*. In order to sustain an environmentally acceptable operation, a document that describes the monitoring plan and the



■ Figure 2. The EIA involves these main process engineering activities. The dotted lines designate rejected alternatives.

roles of involved personnel must be developed.

10. Document and review the EIS. An environmental impact statement documents the EIA process, discussions, findings and recommendations. The EIS should include: an overview of the EIA procedure; project and process descriptions; a baseline characterization of the environment; a list of the alternatives considered; the technical, economic and environmental performance and impacts of the alternatives; the recommended options; and comments on the path forward.

When completed, the EIS is reviewed by the appropriate environmental agency and other decision-makers for final comments and approval. They may approve the project, select one of the project alternatives, require modifications, reject the EIS and require additional studies, or reject all of the proposed alternatives.

Discussions between the company developing the project and the regulatory agency should be ongoing throughout the aforementioned steps to allow meaningful and timely feedback. Public participation should also be solicited before seeking final approval. Post-EIA audits are usually required to verify progress once implementation begins.

Process engineering limitations of typical EIAs

Consider the EIA procedure from the perspective of process engineering activities, as shown in Figure 2. First, various design alternatives are proposed. These design alternatives are normally generated by brainstorming, heuristics, and evolutionary design techniques. Because the number of potential design alternatives is enormous, such approaches generally do not produce an optimum or near-optimum design except in the simplest cases, nor do they generate a rich enough set of alternatives.

The process engineering team must perform a techno-economic analysis and safety assessment (*e.g.*, hazard and operability (HAZOP) or hazard identification (HAZID) analysis) of the alternatives. It must identify, predict and evaluate the environmental impacts of each alternative, and develop mitigation techniques for any unacceptable impacts. If the impacts are acceptable, the EIS is prepared and discussed with decision-makers and the public, which could result in the project being accepted, altered or rejected. The accepted alternatives then become ready for implementation.

This approach has several limitations from a process-engineering standpoint. First, a large number of alternatives may need to be generated and analyzed. Although environmental regulations are typically considered as constraints when generating alternatives, the more-complex environmental effects are not.

For example, an alternative may satisfy certain emissions limits, but the process discharges may interact with other environmental phenomena and neighboring systems in ways that render the overall impact unacceptable. Since these compounded impacts are detected during the impact identification and prediction/evaluation phases of the EIA, it is possible that many alternatives will be rejected during that phase. This is frustrating for the process engineers, since by this time much effort has gone into the generation and analysis of the alternatives.

Process integration can overcome these limitations. It serves as an effective framework for facilitating process-engineering activities associated with the EIA, reducing engineering efforts, providing valuable insights, and systematizing the design effort — while reconciling the various process objectives with the environmental objectives.

The basics of process integration

Process integration is a holistic approach to process design, retrofitting and operation that emphasizes the unity of the process *(7)*. Detailed discussions of process integration can be found in recent textbooks and literature (*e.g.,* Refs. 8–10). Typically, process integration involves four key steps *(9)*:

1. *Task identification* — the explicit expression of the design in terms of actionable tasks.

2. *Targeting* — the identification of performance benchmarks before detailed design. The concept of targeting is one of the most powerful contributions of process integration.

3. *Generation of alternatives (process synthesis)* — the use of process synthesis techniques to effectively identify those alternatives that meet the target at minimum economic and environmental cost.

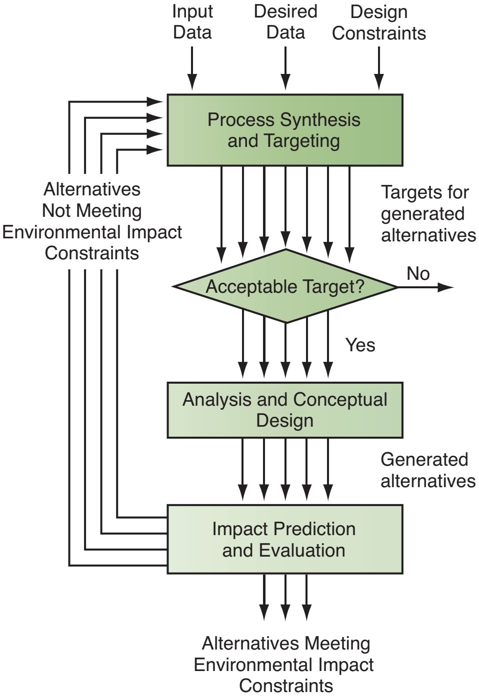
4. *Detailed analysis of selected alternatives* — the use of process analysis techniques (*e.g.,* computer-aided simulation, safety analysis, etc.) to evaluate the alternatives generated based on various performance metrics.

Process integration as an enabling tool for EIA

Process integration can be used to facilitate EIA in several ways: process synthesis to generate alternatives and set targets for environmental-impact benchmarking prior to performing detailed design; "reverse problem" formulation; and integration of alternatives with the rest of the process.

Process synthesis. Instead of employing brainstorming, heuristics, and evolutionary procedures, process synthesis techniques may be used to systematically generate process alternatives. Targeting then determines important benchmarks for the alternatives' performance. Examples of useful targets include:

- minimum fluegas volume *(10)*
- minimum usage of fresh resources and waste discharge *(11, 12)*
- minimum hydrogen production *(13)*
- minimum wastewater generation *(14)*
- minimum VOC emissions from a condensation system *(15)*
- minimum CO_2 emissions from utility systems *(16)*
- minimum usage of external mass-separating agents *(17)*
- minimum consumption of heating/cooling utilities *(8, 18)*
- maximum efficiency of reaction processes *(19–21)*
- maximum efficiency of integrated reaction and separation processes *(22)*.

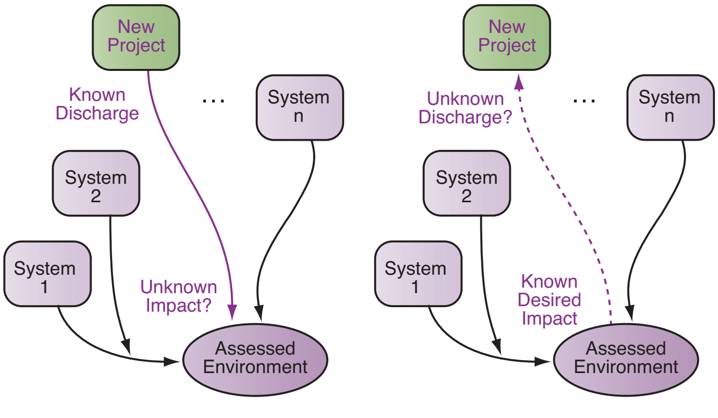


■ Figure 3. Process synthesis and targeting can be applied to EIA.

The advantage of such targets is that they can be evaluated for their environmental impact before detailed design is undertaken. If a target is found to be unacceptable, the time, effort and expense involved in the detailed design and analysis of the alternative is eliminated. The result is a more-effective process and savings in time and effort for the process engineers. Figure 3 represents the proposed targeting and process synthesis approach.

Reverse problem formulation. The typical, or "forward," problem of environmental prediction and evaluation involves quantitatively determining the spatial and temporal consequences of an alternative on the environment while taking into consideration the interaction with various environmental elements and other systems (*e.g.,* neighboring plants, cities, etc.). In such cases, the discharges generated by the alternative are known but their impact on a specific element of the environment at a certain time is unknown.

As mentioned earlier, various means are available to predict and evaluate impacts (*e.g.,* atmospheric dispersion and water quality models *(4–6)*). Some of these may be easily



a. Forward Problem b. Reverse Problem

■ Figure 4. EIA can be applied to the typical (forward) problem of environmental prediction and evaluation, or in reverse.

inverted *(23, 24)* — that is, given an acceptable impact or a constraint on the environment, the prediction/evaluation model may be used, essentially in reverse, to determine the allowable level of discharges. This is referred to as the reverse problem formulation, and it allows appropriate constraints to be incorporated into early process synthesis efforts so that optimum designs with acceptable environmental impacts can be developed from the start. The forward and reverse problems are depicted in Figure 4.

Integration of the alternative with the process. When an alternative is deemed unacceptable during the EIA process, it may be possible to mitigate the undesirable consequences by integrating the alternative with the rest of the process. Although the proposed alternative may not meet EIA criteria on its own, it might become acceptable when it is integrated with the rest of the process.

For instance, suppose that a new piece of equipment produces unacceptable thermal pollution. When it is thermally integrated with the process through the synthesis of a heat exchange network, the thermal pollution may be eliminated cost-effectively by exchanging heat with one or more process cold streams. This possibility could be explored by introducing the appropriate constraints with respect to acceptable thermal pollution into the heat-exchanger-network synthesis activity. Acceptable limits for other forms of pollution can be investigated in a similar manner.

Integrating the alternative with the process may not only mitigate negative environmental consequences, but the efficiency gains associated with the action might improve the profitability of the process. It is also possible to have situations where integration may not be economically justifiable on its own, but when the environmental-mitigation objective is taken into account, integration becomes economically attractive.

Example

Consider the Kraft pulping process *(25)* shown in Figure 5. The throughput of the plant needs to be increased from the current production rate of 1,200 ton/d of bleached pulp to 1,500 ton/d. The plant has sufficient operating capacity to produce 1,500 ton/d with one exception: a bottleneck at the brown-stock washing area, which is currently operating at full capacity. The process engineering team is considering three alternatives: (a) install an additional washer to accommodate a 200-ton/d increase in production; (b) purchase 200 ton/d of unbleached pulp and feed that to the existing bleach plant; or (c) build a smaller Kraft mill to produce the additional 200 ton/d.

Based on an economic analysis, the first alternative is pursued and an EIA study is initiated to understand and address its environmental consequences. In particular, there is a major concern about the discharge of chloride ions in the wastewater streams, which impact a tributary that connects to a drainage system that eventually discharges into a lake.

By taking the reverse-problem approach using a watershed model, it is determined that the maximum allowable discharge load of chlorine from the expanded plant is 15.6 ton/d. Therefore, design efforts focus on reducing the chlorine discharge. Numerous dechlorination technologies are available for end-of-pipe treatment of the wastewater. Possibilities for material substitution in the bleach plant also exist.

Before engaging in laborious techno-economic analysis of the various dechlorination devices and material-substitution options, the engineers examine the feasibility of meeting the target by in-process modification using a low/no-cost strategy of direct recycle (without adding new process equipment). There are four potentially recyclable sources: wastewater from the screener, the multiple-effect evaporator, the concentrator, and the bleach plant. Four potential sinks employ fresh water: the screener, the brown-stock washer, the washer/filter, and the bleach plant operations. Because of quality issues, the bleach plant is not permitted to accept recycled water. Because of the potential buildup of several components as a result of recycle, process models and various technical and environmental constraints must be considered when developing recycle strategies *(25)*. Using mass-integration techniques *(9, 25)*, the target for minimum chloride discharge after direct recycle is found to be 15.2 ton/d. This target is indeed attainable, as illustrated by the flowsheet in Figure 6.

Final thoughts

This integrated approach to EIA offers several important advantages:

- process performance can be benchmarked via rigorous targeting techniques
- the engineer is able to quickly generate and screen project alternatives
- non-promising candidates are excluded from the analysis early
- explicit and implicit environmental constraints are accounted for
- compounded environmental effects are accounted for
- appropriate process changes can be made by inverting environmental constraints on the process and using process integration techniques.

The approach reduces the process engineering efforts required for process retrofitting and for developing EIA studies. Additionally, it provides valuable insights early in the design process and systematizes the design effort, while reconciling the various process objectives with the environmental objectives. **CEP**

MAHMOUD EL-HALWAGI holds the McFerrin Professorship at the Artie McFerrin Dept. of Chemical Engineering at Texas A&M Univ. (230 Jack E. Brown Hall, Texas A&M Univ., College Station, Texas 77843-3122; Phone: (979) 845-3484; Fax: (979) 845-6446; E-mail: el-halwagi@tamu.edu). His main research interests involve process integration, sustainable design, and pollution prevention. He has served as a consultant to a wide variety of chemical, petrochemical, petroleum, pharmaceutical, forestry products, and metal finishing industries, and is an author/editor of four books and numerous publications. El-Halwagi is the recipient of several awards, including the National Science Foundation's Young Investigator Award, the Mortar Board Favorite Educator Award, the Birdsong Merit Teaching Award, the Fred H. Pumphrey Award, the Fluor Distinguished Teaching Award, and the Texas A&M College of Engineering Association of Former Students Distinguished Achievement Award. He holds a BS and an MS from Cairo Univ. and a PhD from the Univ. of California, Los Angeles, all in chemical engineering.

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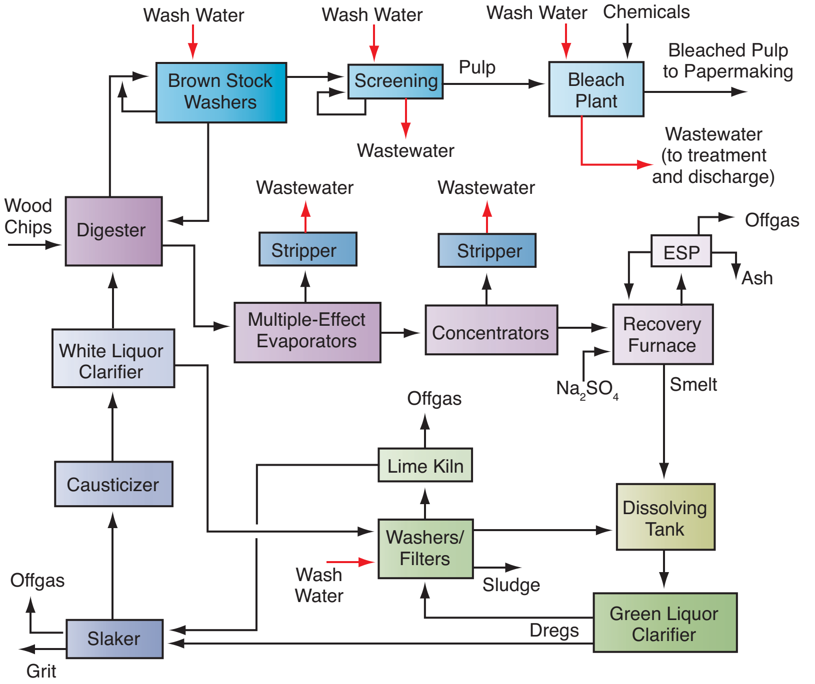
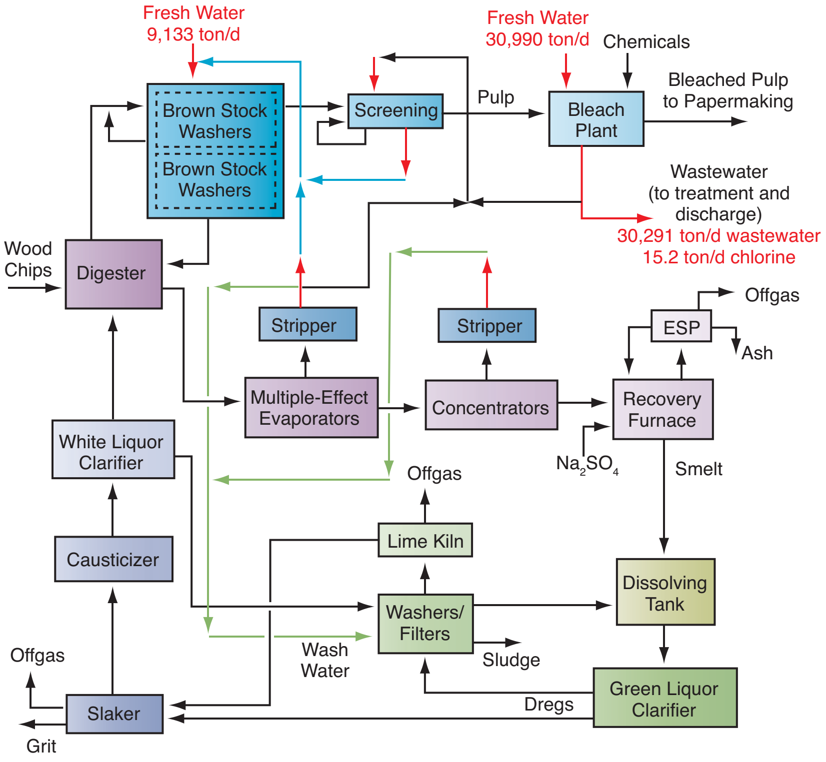


■ Figure 5. The throughput of the pulp and paper plant in the example needs to be increased. Source: *(25).*



■ Figure 6. By incorporating direct recycle, the throughput of the example plant is increased to 1,500 tons/d.

EVA LOVELADY is a process engineer with Mustang Engineering (16001 Park Ten Place, Houston, TX 77084; Phone: (713) 350-7526; E-mail: eva.lovelady@mustangeng.com). Her research is in the field of process design, optimization, multi-scale process synthesis, and sustainability. Previously, she served as an instructor at Texas A&M Univ.-Qatar and worked for several years as a process engineer for ExxonMobil. She has a BS and an MS from Auburn Univ. and a PhD from Texas A&M Univ., all in chemical engineering.

AHMED ABDEL-WAHAB is an assistant professor and program coordinator in the chemical engineering program at Texas A&M Univ.-Qatar (336 Texas A&M Engineering Building, Education City, P.O. Box 23874, Doha, Qatar; Phone: +974-423-0103; Fax: +974-423-0011; E-mail: ahmed-abdel-wahab@qatartamu.edu). He has more than 17 years of experience in environmental engineering research, focusing on chemical processes and treatment methods for water, wastewater, hazardous wastes, contaminated soils and sludges, as well as industrial wastewater recycling and reuse and brine treatment. He currently directs research on environmental impact assessment of industrial cooling water discharge, fate and transport of halogenated organic compounds in seawater, inland desalination with zero liquid discharge, and utilization of modified byproduct sulfur for hazardous waste treatment. He is the author or co-author of many refereed papers in the area of water and wastewater treatment, is a reviewer of several internationally recognized journals, and he has taught short courses on water- and environmental-related topics. Abdel-Wahab is a member of the Environmental Impact Assessment (EIA) Committee of the Qatar Ministry of Environment. He has a BS in civil engineering and an MS in environmental engineering from Almenia Univ. in Egypt and a PhD in environmental engineering from Texas A&M Univ.

PATRICK LINKE is an associate professor of chemical engineering at Texas A&M Univ.-Qatar (Phone: +974. 423.025; Fax: +974.423.0011; E-mail: patrick.linke@qatar.tamu.edu). He develops computer-aided technologies that combine advances in process systems engineering, optimization, and information systems engineering to improve the efficiency of chemical processes in order to promote sustainable "green" alternatives in various sectors of the chemical industries. His research activities focus on the development of efficient and robust optimization-based decision-support methods for complex problem-solving in the process and product systems-engineering domain. Previously, he was a senior lecturer at Surrey Univ., U.K., and a visiting professor at the Technical Univ. of Berlin, Germany. An author/editor of more than a 40 refereed papers, Linke has been involved in funded research projects totaling more than $20 million and has collaborated extensively with numerous multinational companies in the oil and gas and chemical industries. He has a Dipl-Ing in chemical and process engineering from the Univ. of Applied Sciences, Cologne, Germany, and an MS and a PhD in process integration from the Univ. of Manchester Institute of Science and Technology (UMIST).

HASSAN ALFADALA is the Deputy CEO for Operations of Qatari Diar, the organization entrusted with realizing Qatar's vision for sustainable communities and development projects. He has served as the dean of engineering at Qatar Univ. and as the director of the university's Gas Processing Center, a university-industry center with 12 industrial members and numerous affiliates. His main research interests are systems integration, process design, modeling, simulation, optimization, and curriculum reform, and he has extensive experience in the fields of process design and gas processing. He has a BS in gas engineering and an MS in chemical engineering from Texas A&M Univ. and a PhD in chemical engineering from the Univ. of South Florida.

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