When Is IFAS The Right Choice?

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ABSTRACT

The Integrated Fixed Film Activated Sludge (IFAS) technology is gaining popularity in the United States as an alternative strategy for upgrading and expanding municipal wastewater treatment facilities. A number of full-scale IFAS plants are now in operation in the United States, which have demonstrated the technical capability and reliability of the process. The question now being asked by consultants, utility managers, and regulatory agencies is - When Is IFAS The Right Choice? An evaluation carried out to help answer this question considered factors that were believed to be critical in selecting the IFAS technology over other plant upgrading strategies. The evaluation was conducted based on the expansion of a hypothetical plant originally designed for carbonaceous BOD removal and now being upgraded to provide nitrification and denitrification. Five treatment technologies were considered: conventional activated sludge, step feed activated sludge, IFAS, biological aerated filters (BAF), and membrane bioreactors (MBR). Numerous sensitivity analyses were carried out to document how variability in the selected cost factors influence the results of the evaluation. Two case studies are included to show how site specific issues and changes in the cost factors from one location to the next can affect process selection.

KEYWORDS

IFAS, Economics, Nitrification, Denitrification, MBR, BAF, Step-feed

BACKGROUND

Selection of appropriate treatment schemes for wastewater treatment plants is seldomly forthright and based on any one factor. Nonetheless, cost is always important, and this discussion focuses primarily on that factor. Other considerations, however, must also be weighed while making decisions on the myriad of options that are available for plant upgrades, expansions or development from a green field site. These factors generally fall into three general categories identified as treatment concept appropriateness, operations objectives, and design considerations. The most important subcategories of these as they affect consideration of IFAS merit mention here in order to set the playing field straight.

Regarding concept appropriateness, one must consider a number of factors as listed below.

- Site constraints
- Constructability
- Soil conditions
- Condition of existing assets
- Visual and olfactory aesthetics

- Impacts on sludge processing
- Adaptability to anticipated growth

Obviously, site constraints, along with poor soil conditions or high groundwater table and concern over minimizing visual impacts, lead one toward considering small footprint processes, such as IFAS. But at the same time, other small footprint processes may be viable options for consideration. The ability to construct any of the treatment options is critical, particularly if modification or expansion of an existing treatment plant is being considered. Not only is the ability to build the requisite facilities important, but in the case of IFAS where construction is likely needed within existing activated sludge reactor basins – assuming they are structurally fit and in condition for continued use - at least one basin must be offline. Continued plant operation must be feasible with reduced availability of reactor basins for this approach to be viable. Odor control requirements are no more an issue with IFAS than with conventional activated sludge or other aerobic biological treatment processes. IFAS, however, presents an opportunity, along with other small footprint processes, to reduce the size of facilities which must be covered and odor controlled should that be desired. Impacts of IFAS on sludge processing are no different from other activated sludge options, although there is some evidence, depending on a number of design and operating factors, that less waste activated sludge is produced due to the longer retention of solids on the media. Finally, IFAS can easily be adapted to readily address growth potential to a point, as more media can be added to the existing reactor until the upper fill fraction limit is reached. In some cases, this is quite attractive, and supporting facilities, such as the aeration system, must be designed to support the reactor's ability to handle higher loads than those at startup.

Operations objectives also play into process selection. In order to comply with ever-tightening effluent requirements, process robustness is always an attribute. Due to the portion of biomass fixed on the media, the IFAS process has proven to be very robust – resistant to process upset and quick to recover from an upset. Yet the complexity of operation is no different from operating a conventional activated sludge process. Operations staff at Broomfield, Colorado have experienced robust, consistent operation by changing very little and simply letting the growth on the media self regulate to load and seasonal changes. In their opinion, the IFAS process is simpler to operate than conventional activated sludge.

Finally, design considerations that must be investigated during process selection are likely to include the following:

- Wastewater strength and variability
- Climatic impacts
- Screening requirements
- Effluent quality desired = permit limitations

Wastewater strength requires more treatment tankage as the loading increases. As loads increase and at least nitrifying level of treatment is desired, it requires ever-increasing reactor volumes or increased final clarifier area to properly remove and concentrate the MLSS. The addition of media to the reactor and conversion to IFAS makes even more sense with these circumstances. Cold climate, with attendant colder wastewater temperatures, has somewhat the same effect as increasing loadings in that it becomes increasingly difficult to carry a nitrifying sludge age in the system unless very large reactors and final clarifiers are available. Again, IFAS helps mitigate this impact as it allows higher effective SRT in smaller reactors while not imposing the associated solids loading on the final clarifiers because a large proportion of the solids are fixed to the media in the reactor in which they are retained.

With the media retained within the reactor by sieves of relatively small openings, headworks screening must be carefully considered. Most manufacturers of IFAS media recommend screens with maximum openings of 6 mm. Several plants that operate primary clarifiers ahead of the IFAS system have not experienced issues of collecting floatables and plastics in the reactors. Industry practice has been to install finer and finer headworks screens whether IFAS is considered or not. It should be noted that other small footprint processes including MBR and BAF seriously consider 3 mm or finer screens as a pretreatment requirement.

The final design consideration is level of treatment desired to comply with permit limitations. IFAS has proven to exhibit a high level of robustness with minimal variability in effluent quality when compared with activated sludge and other small footprint technologies. Risk is always present with some variations of activated sludge where significant solids loss is a risk or with step-feed bleed-through of ammonia, whereas IFAS mitigates these risks. Furthermore, IFAS presents the opportunity to reach even lower effluent total nitrogen concentrations routinely due to higher levels of simultaneous denitrification within the biofilm attached to the IFAS media. Effluent quality routinely achieved by IFAS should be considered at least equal to activated sludge variations and to other small footprint processes.

The considerations discussed above are extremely important toward process selection. When none of these considerations are compelling toward one option over another, cost is very commonly the selection factor. Recognizing this fact, this paper was prepared to develop a generic comparison of IFAS costs to those for the most popular options to IFAS.

IFAS EVALUATION

An evaluation was conducted to compare the economics of IFAS to several other treatment technologies commonly considered for plant expansions and treatment upgrades. The evaluation was based on upgrading a 25 mgd hypothetical activated sludge process originally designed for carbonaceous-only secondary treatment to provide both nitrification and denitrification. Five treatment technologies were considered: Integrated Fixed Film Activated Sludge (IFAS), Conventional Activated Sludge, Step-feed Activated Sludge, Biological Aerated Filters (BAF), and Membrane Bioreactors (MBR). Conceptual designs and site layouts were developed for the hypothetical plant upgrade for each of the identified technologies. An economic analyses was carried out to first compare the upgrade alternatives on a net present value basis, and then to determine how sensitive the evaluation results are to each of the following six key economic factors:

1. Plant size
2. Peak to average flow ratio

3. Value of land
4. Equipment costs
5. Power
6. Construction costs

The evaluation was conducted on a hypothetical plant to eliminate site specific issues that are commonly experienced with plant upgrades that could favor one technology over the other. These site specific issues need to be carefully considered when selecting a technology for an actual plant upgrade, but the goal for this economic evaluation was to compare IFAS implementation costs to other technologies when there are no special site considerations.

Hypothetical Plant

The hypothetical plant has a design average flow capacity of 25 mgd, a peak to average flow ratio of 2.0, and was designed to treat typical domestic strength wastewater with BOD and TSS concentrations of 250 mg/L and a TKN concentration of 35 mg/L. Primary clarifiers remove 60 percent of the TSS and 35 percent of the BOD, and wastewater temperatures range from 12°C to 25°C with an average temperature of 18°C. The activated sludge process is configured with four aeration basins and four secondary clarifiers and is designed for a 4-day oxic solids retention time (SRT). The overall footprint of the activated sludge process is 3.7 acres.

A summary of the design criteria for the hypothetical plant is summarized in Table 1, and a sketch of the secondary activated sludge process is shown on Figure 1.

Table 1
Hypothetical Plant Design Criteria Summary

	Design Criteria
Flow, mgd	
Average	25
Peak to Ave. Flow Ratio	2.0
Primary Effluent Waste Strength (1)	
BOD, mg/L	163
TSS, mg/L	100
TKN, mg/L	32
RDON(2), mg/L	1.3
Influent Wastewater Temperature, ° C	
range	12 - 25
average	18
Design Load Peaking Factors	
BOD	1.5
TKN	1.3
Activated Sludge Process	
SRT, days	4.0

(1) primary clarifier removal rates of 60 percent TSS and 35 percent BOD
(2) RDON = Refractory Dissolved Organic Nitrogen, i.e. soluble TKN unavailable for biological treatment.

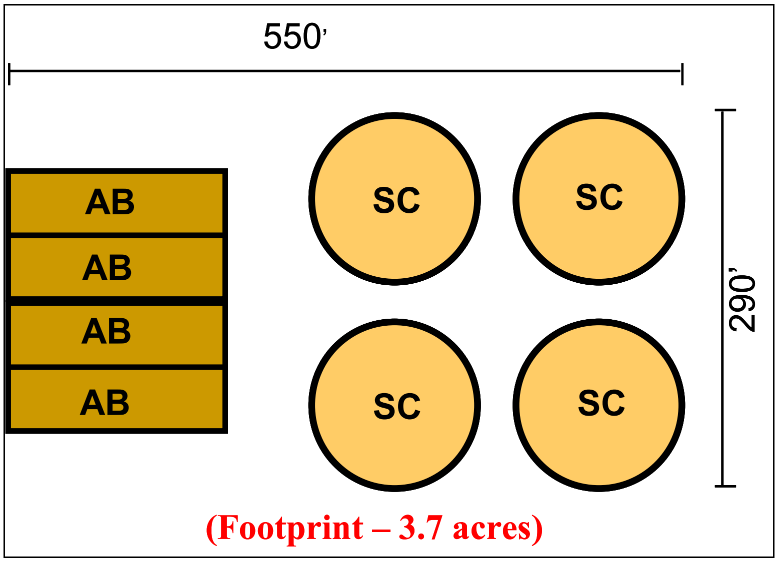

Figure 1 – Hypothetical 25 mgd Activated sludge Process

The treatment requirements for the hypothetical plant upgrade include a total inorganic nitrogen (TIN) limit of 6.0 mg/L, and BOD and TSS limits of 20 mg/L. To maintain reliable nitrification and denitrification at the minimum wastewater temperature of 12°C, the design criteria for the plant upgrade includes a minimum oxic SRT of 10 days and a minimum anoxic zone hydraulic retention time (HRT) of 1.3 hours.

Upgrade Alternatives

The evaluation considered five alternatives for the plant upgrade: IFAS, conventional activated sludge, step-feed, biological aerated filters (BAF), and membrane bioreactor (MBR). Conceptual process designs and site layouts were developed for each of the five alternatives as discussed in the following paragraphs.

IFAS Alternative. The conceptual design for the IFAS alternative is based on converting the activated sludge aeration basins to IFAS reactors configured with an anoxic zone and two oxic media zones in series as shown schematically on Figure 2. Mechanical mixers are included for the anoxic zones and designed to maintain a mixing energy of 0.45 brake horsepower per thousand cubic feet (bhp/kcf) of liquid volume. Two internal structural walls create the two oxic zones in series, both of which have a media fill fraction of 62 percent. Media is not placed in the anoxic zones. Media retention sieves are mounted in the internal walls to allow the mixed liquor suspended solids (MLSS) to pass through the basins while retaining the media. Submersible mixed liquor recycle pumps convey a recycle of up to 4 times the design average flow from the end of the aeration basins to the front of the anoxic zones. The existing in-basin diffused aeration system is replaced with a new coarse bubble diffused aeration system configured to maintain uniform distribution of the IFAS media. As shown on Figure 2, all of the IFAS improvements would be internal to the existing aeration basins, so no additional site footprint is required for this alternative.

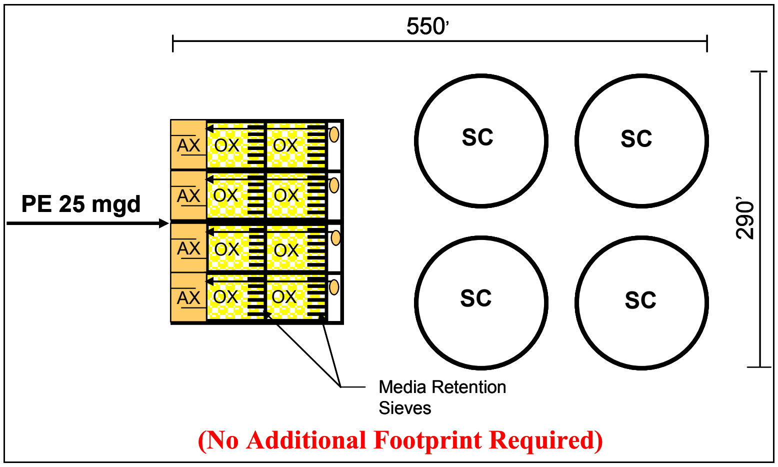

Figure 2 – IFAS Nitrification/Denitrification Upgrade Alternative

Conventional Activated Sludge Alternative. The conventional activated sludge alternative requires seven new aeration basins as shown on Figure 3. A new flow distribution structure diverts 16 mgd of the design average flow and corresponding peak flows to the new aeration basins that provide the additional volume necessary to achieve an oxic SRT of 10 days and an anoxic zone HRT of 1.3 hours. The anoxic zones are equipped with mechanical mixers to maintain a mixing energy of 0.45 bhp/kcf of liquid volume. Submersible mixed liquor recycle pumps convey a recycle of 4 times the design average flow from the end of the aeration basins to the front of the anoxic zones. As shown on Figure 3, the conventional activated sludge alternative requires an additional site footprint of approximately 2.1 acres.

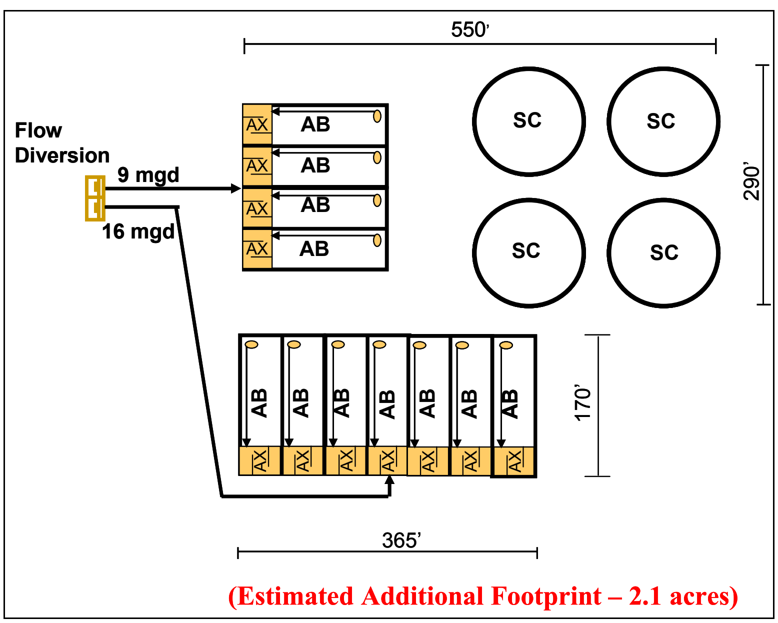

Figure 3 – Conventional Activated Sludge Upgrade Alternative

Step-feed Activated Sludge Alternative. The step-feed activated sludge alternative requires five new aeration basins as shown on Figure 4. A flow distribution structure diverts 14 mgd of the design average flow and corresponding peak flows to the new aeration basins. Three step-feed points are provided in each aeration basin: the first at the front of the aeration basin, the second at the 1/3rd point, and the third at the 2/3rd point down the length of the basin. Anoxic zones are created at each step-feed point with concrete baffles. As shown on Figure 4, the step-feed alternative requires an additional site footprint of approximately 1.5 acres.

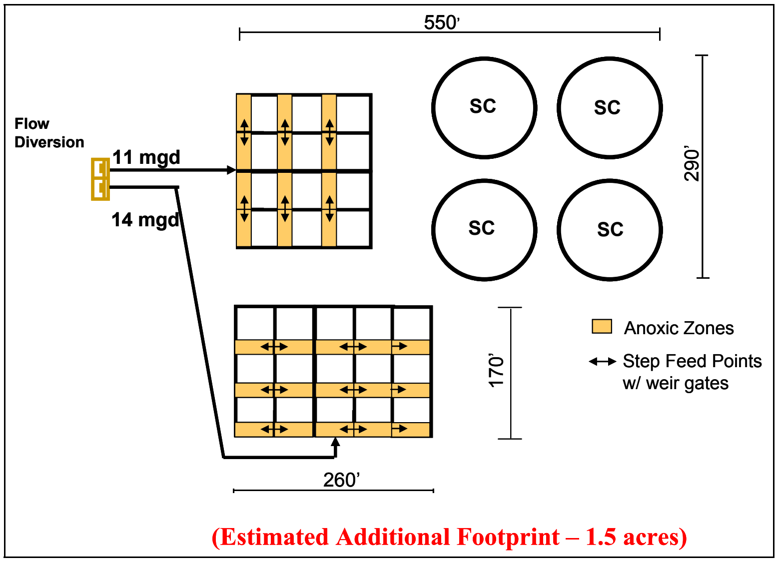

Figure 4 – Step-feed Activated Sludge Upgrade Alternative

BAF Alternative. The BAF alternative diverts 12.5 mgd of the design average flow and the corresponding peak flows to a newly constructed BAF treatment train as shown on Figure 5. An intermediate pumping station provides the necessary lift to allow gravity flow through the BAF treatment train. The existing activated sludge process is upgraded to provide full nitrification and denitrification of the remaining 12.5 mgd of the design average flow. The 4 activated sludge basins in this option treat more flow than they could in the conventional upgrade option because the entire existing clarifier capacity is available and can be operated at solids loading rate conditions thereby allowing the system to operate at a higher MLSS. The activated sludge process improvements include anoxic zone baffle walls, mechanical mixers for the anoxic zones, and mixed liquor recycle pumps based on the criteria discussed above for the conventional activated sludge alternative.

As shown on Figure 5, the BAF treatment train consists of a two-stage BAF process that requires an additional site footprint of approximately 1.1 acres. The first BAF stage provides both organic (BOD_5) removal and nitrification and a moderate level of denitrification by recycling nitrified water to anoxic zone located at the base of the up-flow BAF reactor. The second stage BAF process provides post denitrification to remove an additional 4 to 5 mg/L of nitrate to meet the target effluent TIN concentration of 6.0 mg/L. Methanol is used in the post BAF process to provide the carbon source needed to support denitrification.

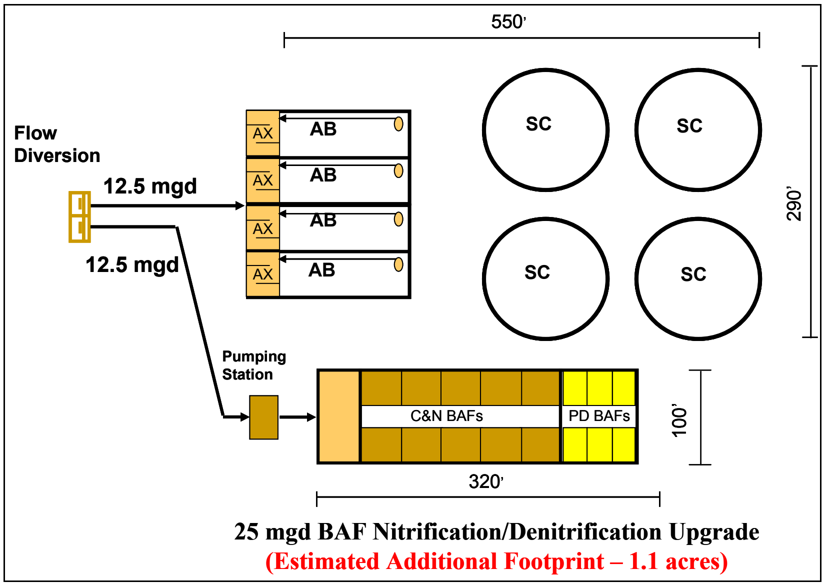

Figure 5 – BAF Upgrade Alternative

MBR Alternative. The MBR alternative requires a new MBR reactor to work along with the existing aeration basins as shown on Figure 6. The aeration basins are modified to include anoxic zones equipped with mechanical mixers and mixed liquor recycle pumps based on the criteria discussed above for the conventional activated sludge alternative. The existing secondary clarifiers are taken out-of-service. A high rate of recycle flow is required from the MBR reactor back to the aeration basins to a point just downstream of the anoxic zones, which is necessary to maintain a uniform distribution of mixed liquor solids. The MBR process is conceptually designed to maintain a minimum oxic SRT of 15 days and a maximum MLSS concentration of 10,000 mg/L. As shown on Figure 6, the MBR alternative requires an additional site footprint of approximately 0.6 acres.

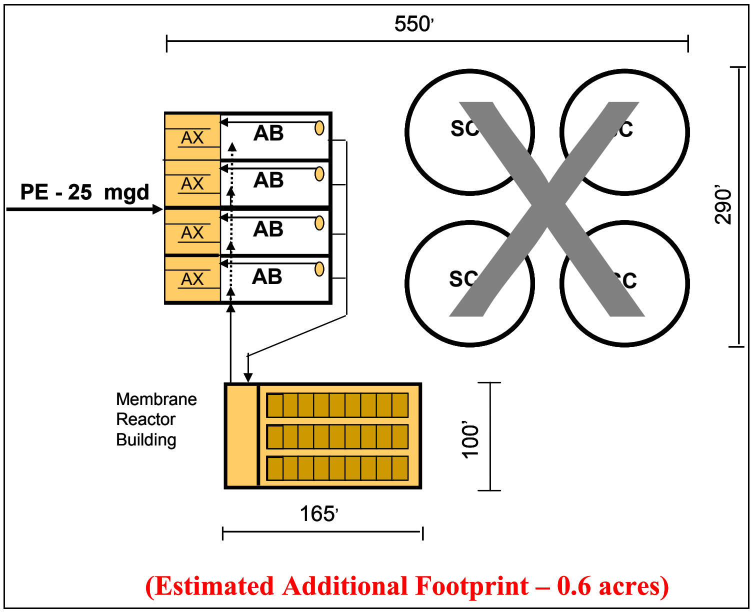

Figure 6 – MBR Upgrade Alternative

Life Cycle Cost Analysis

A life cycle cost analysis was performed to compare the upgrade alternatives on the basis of net present value (NPV). The evaluation was carried out based on a 20-year project life and a discount rate of 3 percent. Capital cost opinions were developed from cost curves, unit cost factors, cost information received from equipment manufactures, and cost information developed for projects with similar facilities. Operation and maintenance (O&M) costs were limited to power, chemicals, and special maintenance requirements for the treatment technologies. The costs should be considered study level estimates with appropriate accuracy for the general comparison of the alternatives.

A comparison of the NPVs for the five upgrade alternatives is shown graphically on Figure 7. The IFAS, conventional, and step-feed alternatives have similar NPVs that vary by approximately 20 percent. This small difference is only marginally above what would be considered significant for study level cost estimating. The NPV for IFAS is considerably lower than that for MBR and BAF, which are the other two small footprint technologies usually considered when there are site constraints or restrictions that will not allow the use of conventional processes.

The cost components of the respective NPVs are equipment costs, construction costs, and O&M costs. The cost components are represented graphically on Figure 7 for each alternative. The IFAS alternative has considerably lower construction costs but higher equipment costs than the conventional and step-feed alternatives, which is reasonable since no additional structures are required for IFAS. O&M costs for the alternatives were found to be very similar with the exception of the MBR alternative. It is also interesting to note that the construction costs for conventional activated sludge and step-feed are very similar, which indicates that the cost savings experienced with step-feed as a result of building less new aeration volume is off-set by the additional costs associated with the flow distribution channels and weir gates and controls necessary to step-feed the basins.

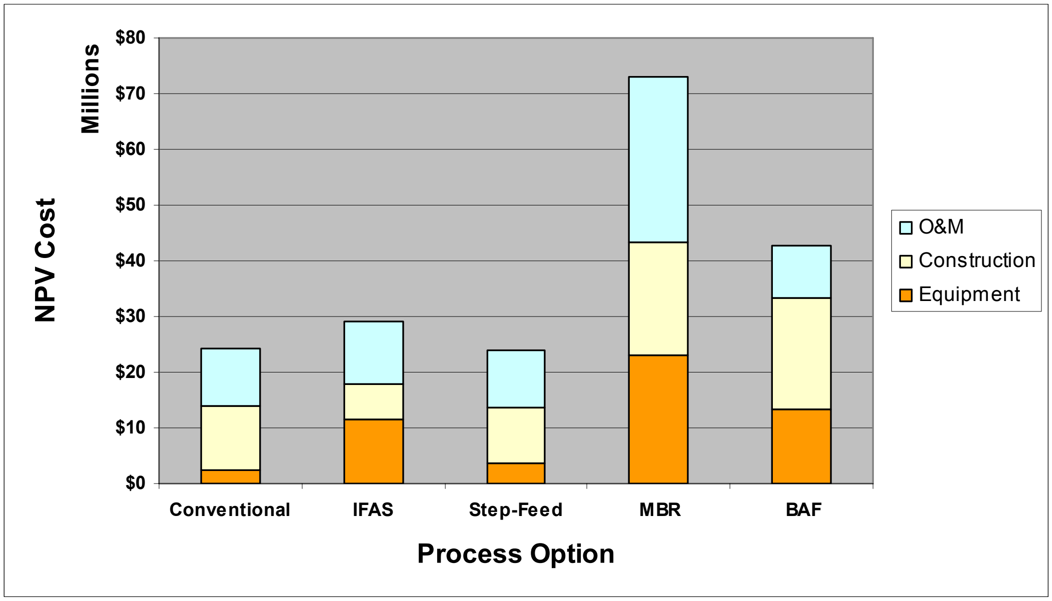

Figure 7 – Net Present Value Cost Breakdown

Sensitivity Cost Analysis

Many different factors contribute to the overall project life cycle cost for wastewater treatment systems. When selecting a treatment plant upgrade technology, all of these factors must be considered, and, depending on their value, an increase in a particular cost factor may have a greater impact on one technology than another.

Many of these cost factors are significantly different from site to site and their historical trends show a general increase over time. If the increases are gradual and somewhat in line with inflation, they can easily be accounted for by the cost estimator in the technology alternative evaluations. If the costs are more erratic or show a more rapid increase, the estimator's task becomes more difficult.

The most significant factor affecting the *operating* costs of most wastewater treatment plants is the cost of electricity, typically expressed as cents/kWh. The cost of electricity varies widely from state to state, as shown on Figure 8, depending on the market forces of supply and demand and other factors. In Kentucky, where demand is relatively low and there is a ready source of electricity from coal-fired power stations, the average price of electricity in 2005 was only 4.9 cents/kWh. Conversely, in the northeastern states where demand is much higher, the costs are also much higher; with New York State topping the charts for the contiguous US states at 13.2 cents/kWh as an average for 2005. Only Hawaii was more expensive at 18.3 cents/kWh. A thorough understanding of local electricity prices and rate structures is imperative in evaluating operating costs.

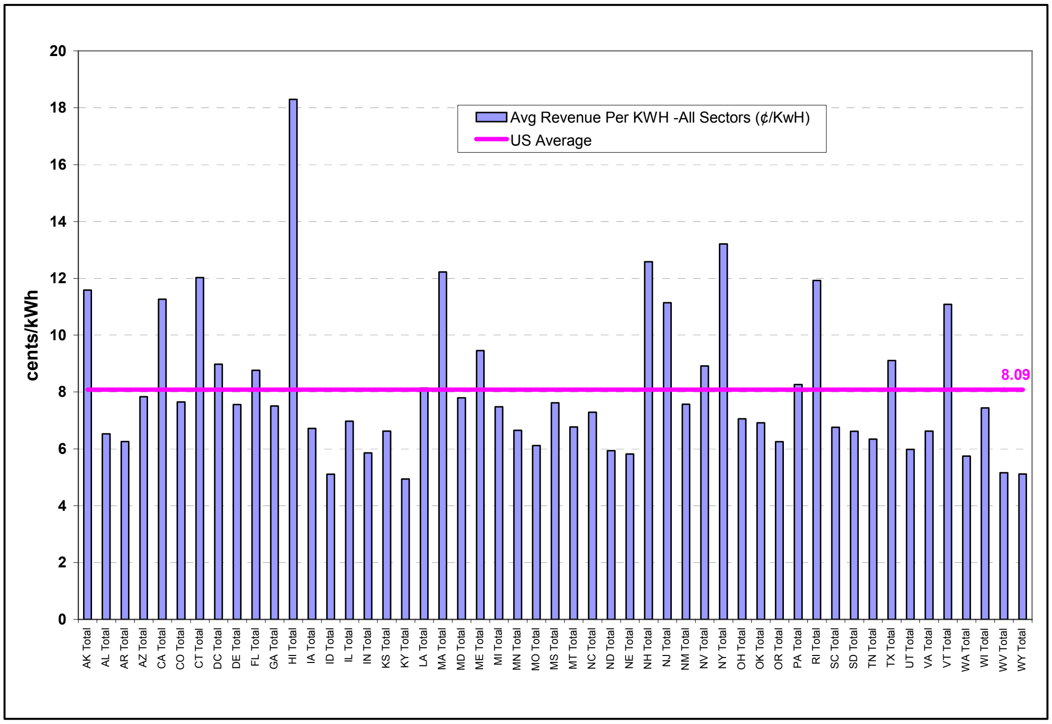

Figure 8: 2005 Average Electricity Price by State

Historically through the 1990s, US electricity prices remained relatively constant and in some states even showed a slight decline. However, as can be seen on Figure 9, electricity prices have become much more volatile in many states in the last six years. The deregulation of electricity in California around the turn of the century caused perhaps the most noted increase in electricity costs in recent years. Texas and many northeastern states have seen similar jumps in electricity costs in the past year. Overall the US average cost for electricity has risen from under 7 cents/kWh through most of the 1990s to over 8 cents/kWh by the end of 2005.

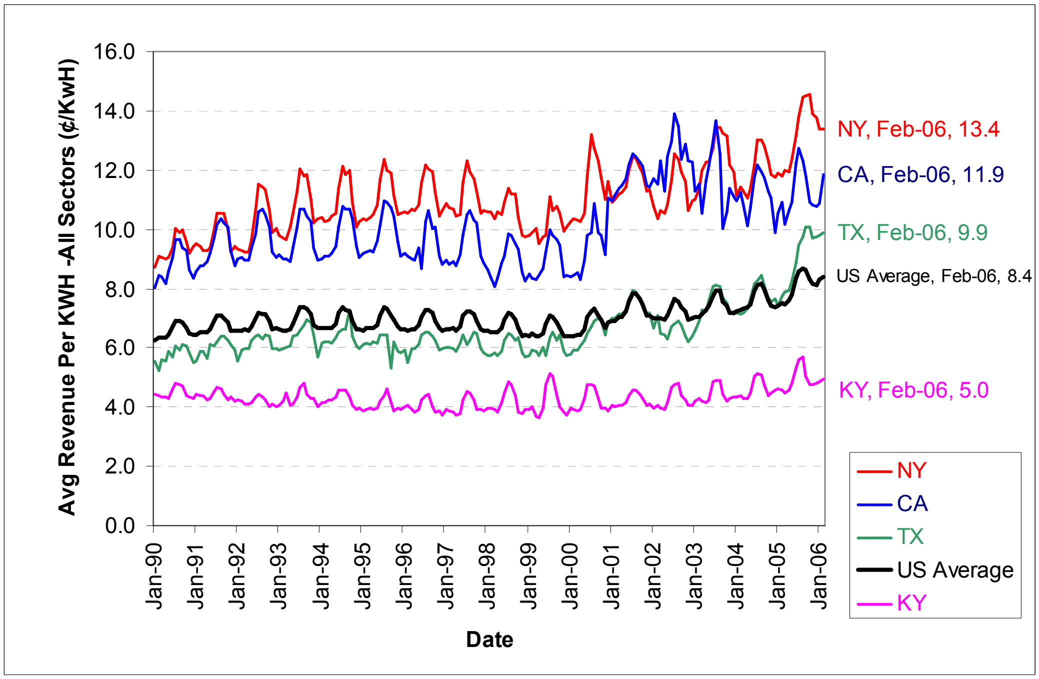

Figure 9: Monthly Average Electricity Prices US and Selected States (January 1990 - February 2006)

In recent years the cost of construction materials, such as steel and cement, has increased significantly. The producer price index (PPI) for US construction materials is shown on Figure 10. The cost of materials has increased notably and dramatically since the end of 2003. It would be expected that construction costs would also increase in line with the cost of construction materials, however, the most significant portion of the cost of construction is in labor, not materials which means the increase is somewhat tempered.

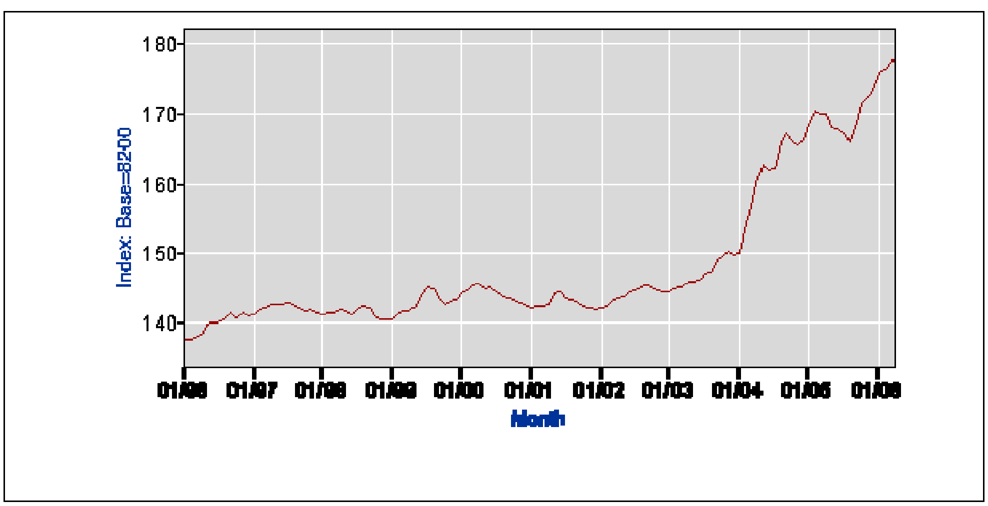

Figure 10: Producer Price Index (PPI) for Construction Materials (Id=WPUSI012011, Base Date=1982)

The ***Engineering News Record*** (ENR) produces several cost indices including the Building Cost Index (BCI). The BCI includes labor and material costs from 20 major US cities in order to track building costs. ENR defines the BCI as the cost of "*68.38 hours of skilled labor at the 20-*

city average of bricklayers, carpenters and structural ironworkers rates, plus 25 cwt of standard structural steel shapes at the mill price prior to 1996 and the fabricated 20-city price from 1996, plus 1.128 tons of portland cement at the 20-city price, plus 1,088 board-ft of 2 x 4 lumber at the 20-city price." The US average BCI from 1990 until the beginning of 2006 as well as the BCI for four major cities for the same period is shown on Figure 11. The BCI has gradually increased over this time with a notable increase in 2004 (though less dramatic than the Construction Materials PPI). Differences in BCI between specific cities is dramatically pronounced. The current BCI for New York City is 6299, compared to the US average of 4331 and the Dallas value of only 3180, the latter roughly half the BCI for New York City!

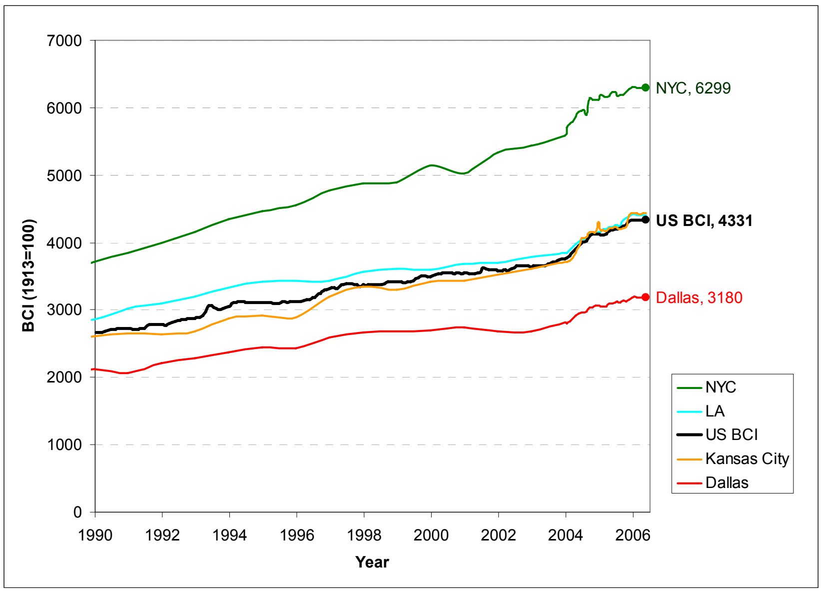

Figure 11: Historical BCI for US and Select Cities (NYC=New York City, LA = Los Angeles)

So, how will increasing energy costs and construction costs affect the selection of wastewater treatment processes, particularly for upgrading carbonaceous plants to achieve nutrient removal? How do regional cost variations affect the selection? These are the subjects of the analyses presented in this paper.

A primary goal for the economic evaluation was to identify the factors that have a high influence on the economic viability of IFAS, and to investigate how the results of the life cycle cost analysis would change given a reasonable amount of variability in these factors. To accomplish this goal, a number of sensitivity analyses were carried out for six selected economic factors as summarized in Table 2.

Table 2 Economic Factors for Sensitivity Analyses				
Economic Factor	Units	Minimum	Median	Maximum
Plant Size	mgd	5	25	100
Peak/Ave Flow Ratio	---	1.5	2.0	3.0
Value of Land	$/acre	25,000	500,000	2,500,000
IFAS Equipment	$/cf media	5	15	25
Power	$/kWh	0.04	0.07	0.15
Construction Index (BCI)	Index	3370	4330 (1)	6500

(1) April 2006 National Average

The results of the sensitivity cost analysis are shown graphically on Figures 12 through 17, and the following paragraphs discuss the results for each economic factor.

Plant Size. The results of the plant size sensitivity analysis are shown on Figure 12. Three plant sizes were considered: the original 25 mgd hypothetical plant, a smaller 5 mgd plant, and a larger 100 mgd plant. The basis of design for the smaller and larger plants remained the same as that shown in Table 1 for the 25 mgd hypothetical plant upgrade, and the plant size was the only economic factor changed – all other factors remained the same as that shown in Table 2 for the 25 mgd plant.

As demonstrated on Figure 12, implementation costs for IFAS, conventional activated sludge, and step-feed are very similar for smaller plants, but as the plant size increases above 15 mgd conventional and step-feed activated sludge have a small economic advantage. One explanation for this is that as plant size increases, larger basins are constructed resulting in an economy of scale cost adjustment that drives the cost per unit volume lower for the larger plants. The MBR technology becomes less economical as plant size increases, while the cost differential between the IFAS and BAF technologies remains relatively constant.

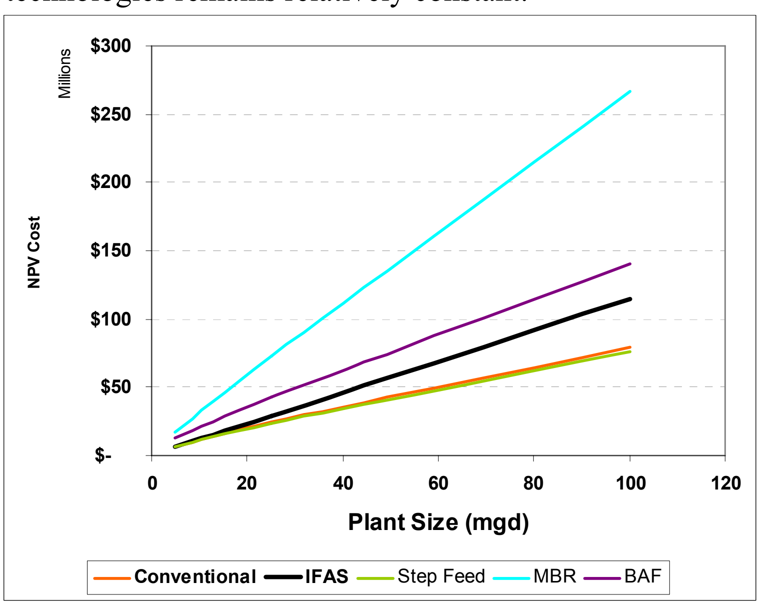

Figure 12 – Plant Size Sensitivity Analysis

Land Value. The results of the land value sensitivity analysis are shown on Figure 13. Three land values were considered over a wide range: $500,000/acre as used for the life cycle cost analysis for upgrading the 25 mgd hypothetical plant, a lower value of $25,000/acre, and a higher value of $2.5M/acre. All other factors were held constant at the values shown in Table 2 for the 25 mgd plant.

The NPV for IFAS is not affected by land cost variability because all improvements are internal to the existing basins, so no additional footprint is required. All other alternatives were affected by land cost variability based on the required additional footprint for their implementation: 2.1 acres for conventional activated sludge, 1.5 acres for step-feed, 1.1 acres for BAF, and 0.6 acres for MBR. IFAS implementation costs were found to be equivalent to those for conventional activated sludge and step-feed at a land value of roughly $1.75M and $2.5M, respectively.

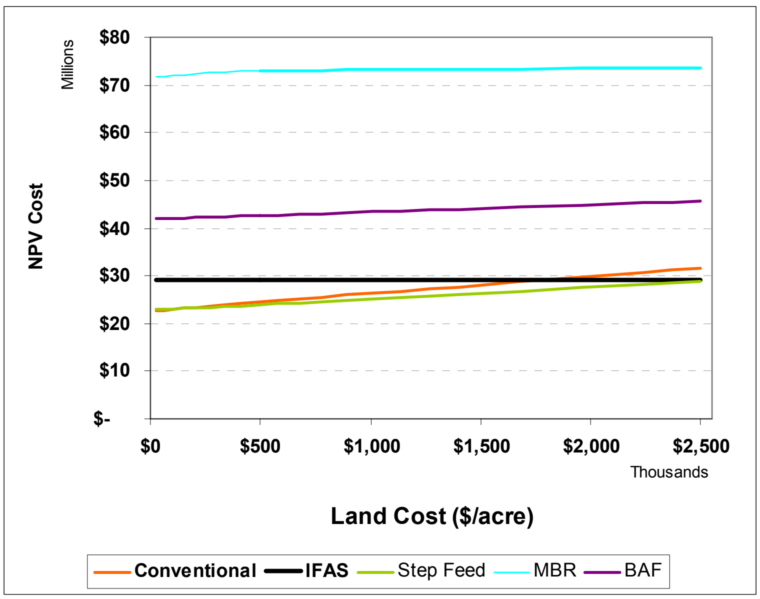

Figure 13 – Land Value Sensitivity Analysis

Construction Cost Index. The results of the construction cost sensitivity analysis are shown on Figure 14. Three BCI values were considered: the April 2006 BCI of 4330 as used for the life cycle cost analysis for upgrading the 25 mgd hypothetical plant, a lower value of 3370, and a higher value of 6500; these extremes representing a rough projection of indices for Dallas and New York City, respectively. All other cost factors were held constant at the values shown in Table 2 for the 25 mgd plant upgrade.

As shown on Figure 14, IFAS costs are only marginally affected by variability in the BCI while all other alternatives are much more sensitive to this factor. This is reasonable considering the IFAS improvements require very little concrete work relative to the other alternatives. IFAS implementation costs were found to be equivalent to those for conventional activated sludge and step-feed at a BCI of approximately 6500. The BCI for New York City (NYC) for April 2006 was 6300 and is indicated on the figure. The selection of IFAS is increasingly favorable in regions with higher construction costs.

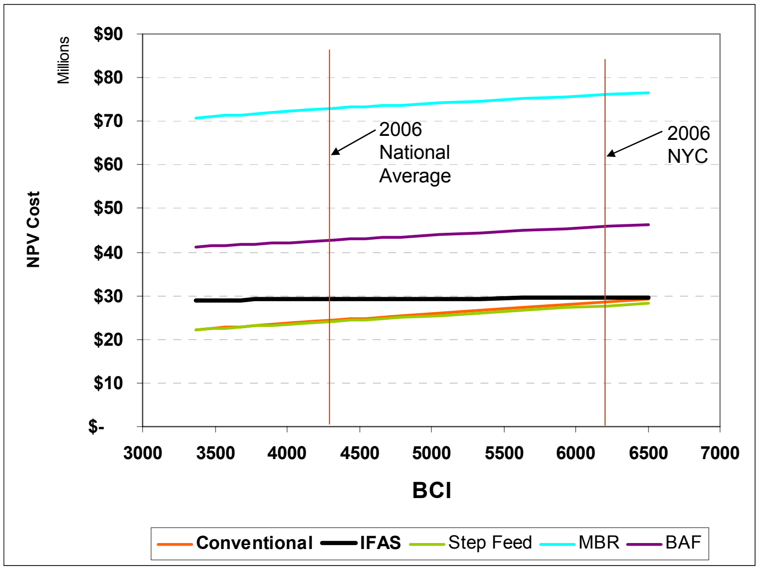

Figure 14 – Construction Cost Index (BCI) Sensitivity Analysis

Peak Flow Factor. The results of the peak flow sensitivity analysis are shown on Figure 15. Three peak to average flow ratios were considered: the 2.0 ratio used for the 25 mgd hypothetical plant, a lower factor of 1.5, and a higher factor of 3.0. As illustrated on Figure 15, peak flows have a significant effect on the MBR costs, a slightly lesser impact on the BAF alternative, and very little effect on conventional activated sludge, step-feed and IFAS, which is reasonable considering that the project costs were developed for upgrading an existing activated sludge process with adequate clarifier capacity to handle the design peak to average flow ratio. It should be noted, however, that the media retention sieve design and costs were adjusted to be appropriate for the lower and higher peak to average flow ratios. This is not evident on Figure 15 because the media retention sieve costs are relatively insignificant in comparison to the overall NPV for the IFAS alternative.

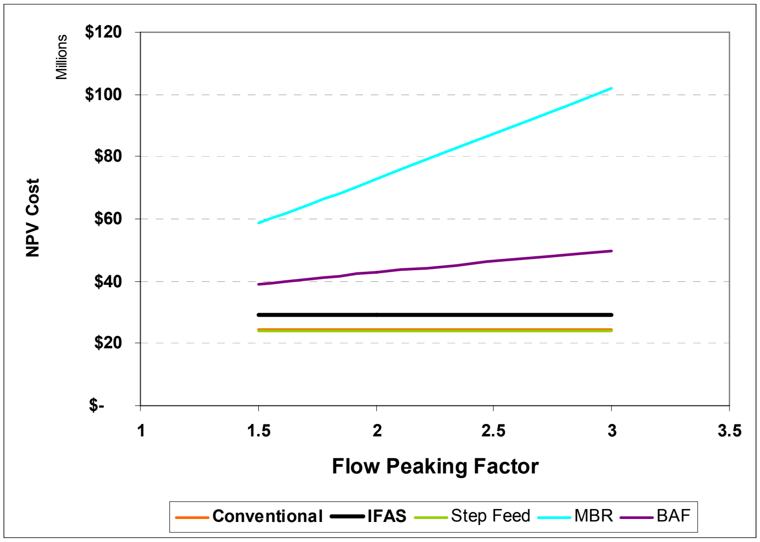

Figure 15 – Peaking Factor Sensitivity Analysis

IFAS Media Cost. The results of the IFAS media cost sensitivity analysis are shown in Figure 16. Three media cost values were considered: $15/cf as used for the life cycle cost analysis for upgrading the 25 mgd hypothetical plant, a lower value of $5/cf, and a higher value of $25/cf. All other cost factors were held constant at the values shown in Table 2 for the 25 mgd plant upgrade.

As would be expected and shown on Figure 16, the NPV for IFAS is greatly affected by the cost of IFAS media. At a media cost of approximately $10/cf, IFAS implementation costs are equivalent to those for conventional activated sludge and step-feed. The BAF technology becomes a more cost-competitive alternative when media costs approach $25/cf.

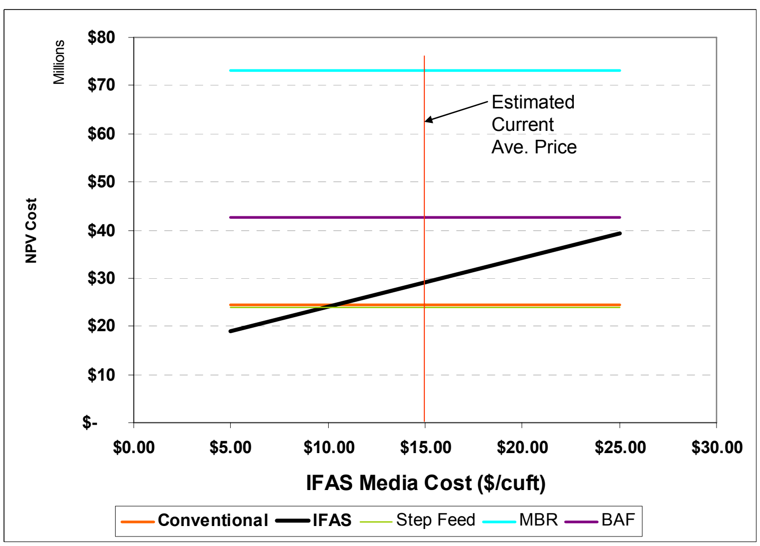

Figure 16 – IFAS Media Cost Sensitivity Analysis

Power Costs. The results of the power cost sensitivity analysis are shown on Figure 17. Three power cost values were considered: the $0.07/kWh used for the life cycle cost analysis for upgrading the 25 mgd hypothetical plant, a lower value of $0.04/kWh, and a higher value of $0.15/kWh. All other cost factors were held constant at the values shown in Table 2 for the 25 mgd plant upgrade.

Power costs affect the NPV of IFAS, conventional activated sludge, and step-feed in much the same way, which was somewhat unexpected because a coarse bubble diffused aeration system was used for the IFAS alternative while fine bubble was used for the conventional activated sludge and step-feed alternatives. It was found that the conventional and step-feed alternatives operate under mixing air limitation at the average loading condition, which resulted in similar power requirements to the coarse bubble system supporting the IFAS alternative. The MBR technology, however, is more sensitive to variability in power costs due to additional power requirements for membrane scour air and an increased endogenous respiration oxygen demand resulting from operating at a longer SRT.

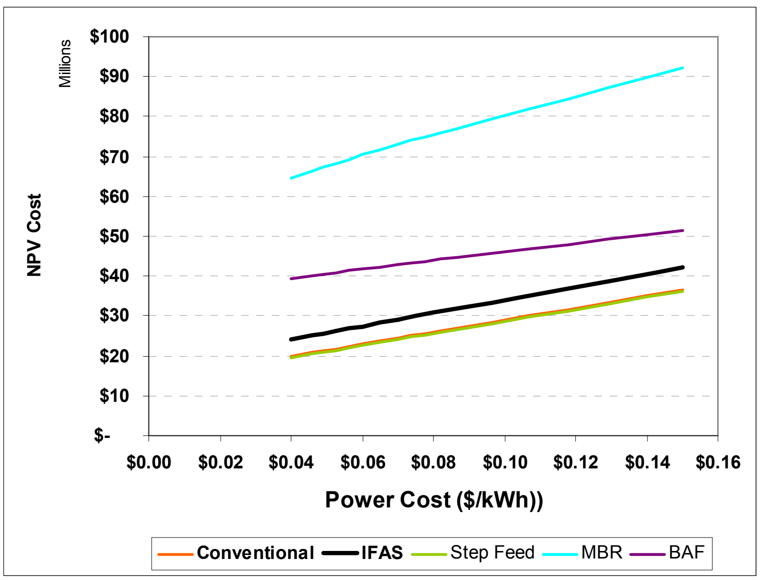

Figure 17 – Power Cost Sensitivity Analysis

The results of the sensitivity analyses indicate that only four of the six economic factors under consideration have a significant affect on the economic viability of IFAS, namely:

(1) Plant size
(2) Construction costs
(3) Land value
(4) IFAS media cost

Of these, the IFAS media cost and construction costs are the most significant.

CASE STUDIES

Two case studies are included to further demonstrate how variability in construction costs and IFAS media costs can affect the economic viability of IFAS.

West Haven, CT - Water Pollution Control Facility

A facility planning study was conducted for the West Haven Wastewater Pollution Control Facility (WPCF) during 2003-04 with the primary focus of developing a plan to expand the plant to meet future capacity requirements, and to upgrade the plant to provide a high level of nitrogen removal. For West Haven to meet its nitrogen waste load allocation (WLA) through treatment alone, rather than relying on purchasing nitrogen credits for a portion of their WLA, the plant must produce an annual average effluent total nitrogen (TN) concentration of 4.4 mg/L. With the flexibility offered by the Connecticut nitrogen credit trading program, the facility planning study was focused on finding the most economic balance between treatment and purchasing nitrogen credits.

The West Haven WPCF is located adjacent to New Haven Harbor as shown on Figure 18. The plant has physical site constraints due to tidal wetlands to the north, south and east, and a public street to the west. The existing secondary treatment process is also challenged with poor performing shallow rectangular clarifiers. The recommended treatment strategy had to consider the limitations of these clarifiers and control the clarifier loadings, both hydraulic and solids, to reasonable levels.

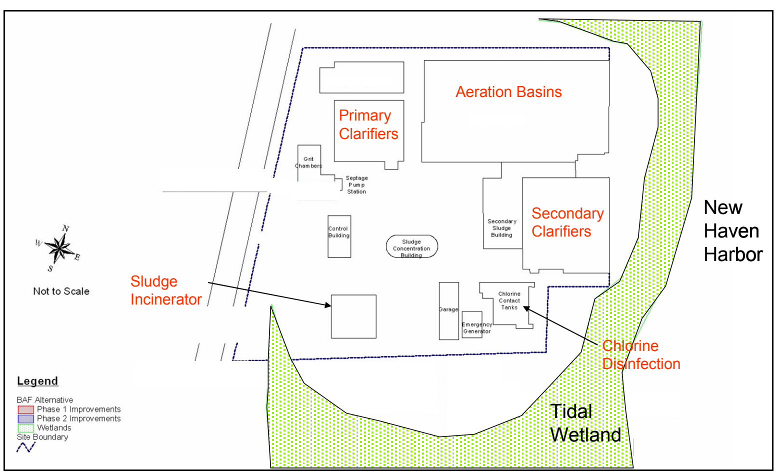

Figure 18 – West Haven WPCF Site Plan

With the site constraints and the condition of the existing facilities, it was not possible to consider conventional activated sludge or step-feed for the West Haven plant expansion and upgrade project. Consequently, three small footprint technologies were considered: IFAS, MBR, and BAF. The IFAS alternative includes modification of the existing aeration basins to IFAS reactors configured with anoxic zones, mixed liquor recycle pump, and two oxic IFAS media zones in series. A ballasted flocculation process is included with the IFAS alternative to treat wet weather flows; flows which would overload the existing secondary clarifiers.

The MBR alternative includes the installation of the membranes in the existing secondary clarifier basins, and modification of the existing aeration basins to a Four-stage Barndenpho configuration. A ballasted flocculation process is also included with the MBR alternative to reduce the membrane surface area required to handle the peak wet weather flows.

The BAF alternative is based on providing a parallel BAF treatment process to off load the existing activated sludge process such that it would be able to provide full nitrification and denitrification in a two-stage nitrification/denitrification configuration. The BAF treatment process is designed to provide both nitrification and moderate denitrification with a high rate of internal recycle back to an anoxic zone located at the base of the upflow BAF process. During wet weather periods, the high internal recycle is turned off to provide additional hydraulic capacity to allow a large portion of the wet weather flow to be handled through the BAF process, so the existing activated sludge process does not have to handle excessive wet weather flows.

The facility planning study recommended that the IFAS alternative be implemented for the West Haven plant expansion and upgrade project. The economic evaluation developed during the study was revisited to determine how variability in construction costs and IFAS media costs would affect the results of the original life cycle cost analysis. Figure 19 shows the result of the construction cost index sensitivity analysis. The original project cost estimates were prepared in 2003 when the BCI was approximately 3750. Project cost opinions for each alternative were adjusted based on a lower BCI of 3000 and a higher BCI of 6500. As shown on Figure 19, the IFAS alternative becomes more economical relative to the other two alternatives as the BCI increases. This is consistent with the findings of the hypothetical plant analysis, and likely the result of much less concrete work being required for the IFAS alternative.

The BAF technology was found to be a much more cost-competitive option for the West Haven project than it was for the hypothetical plant upgrade. Flexibility provided by the Connecticut nitrogen credit trading program made it possible to provide only a single stage BAF process rather than the two-stage process required for the hypothetical plant upgrade, which was necessary to comply with the TIN limit of 6.0 mg/L. The West Haven IFAS alternative costs were also increased due to the wet weather flow ballasted flocculation process included with this alternative.

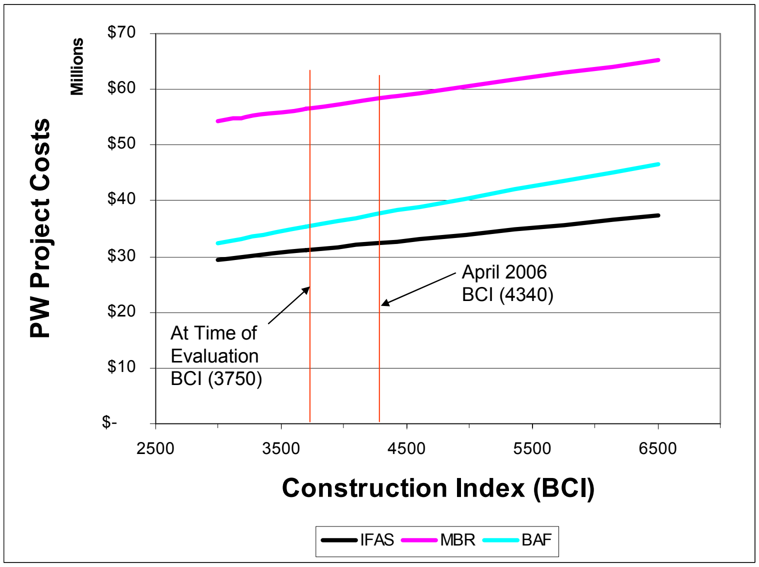

Figure 19: BCI Sensitivity Analysis for West Haven

The result of the IFAS media cost sensitivity analysis for West Haven is shown on Figure 20. IFAS media costs were estimated at approximately $15/cf of bulk media when the cost evaluations were prepared for the West Haven study. With a media cost of $15/cf, the IFAS alternative was the most cost-favorable alternative by approximately $5.0M on a present worth basis. The IFAS alternative for West Haven becomes more economical as IFAS media costs come down, and remains the most economical alternative up to a media cost of approximately $22/cf.

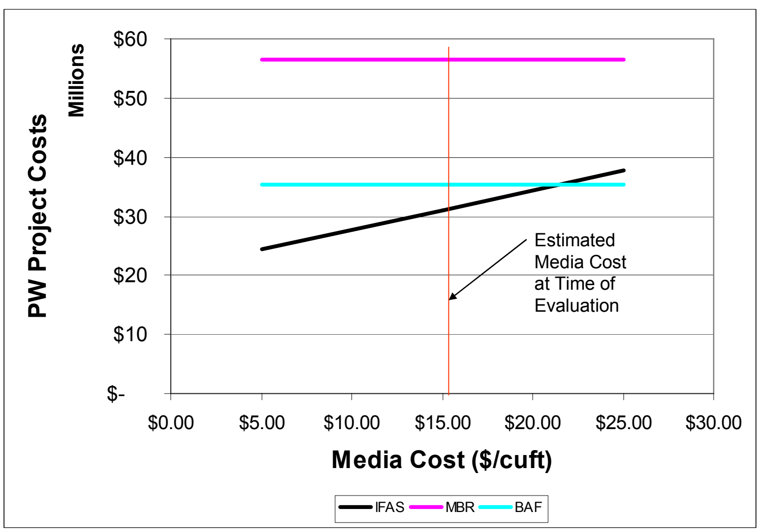

Figure 20 – West Haven IFAS Media Cost Sensitivity Analysis

Although IFAS was found to be the most cost-favorable option for West Haven, there are a number of other considerations that support the implementation of this technology. IFAS will significantly increase the process reliability of the plant because it will reduce the solids load on the existing final clarifiers while increasing the oxic SRT, and will prevent the washout of nitrifying bacteria during peak wet weather flows. The IFAS technology also often achieves a significant level of simultaneous nitrification/ denitrification which will help the City meet their nitrogen WLA through treatment rather than purchasing nitrogen credits.

Norwich, CT – Wastewater Treatment Facility

A facility planning study for the Norwich WWTF was initiated in 2002 with the primary focus of developing a cost-effective plan for expanding and upgrading the plant to meet its future service requirements. Flow projections for 2023 require that the improvements be designed with an annual average flow capacity of 10.3 mgd. The Norwich facility faces similar treatment challenges as those discussed previously for the West Haven plant. For Norwich to meet their nitrogen WLA through treatment, the plant must produce an annual average effluent TN concentration of 3.5 mg/L. A high concentration of ammonia is returned to secondary treatment from the anaerobically digested sludge dewatering facility which further adds to the challenge of achieving a very low effluent TN concentration. The facility must also handle very high peak wet weather flows resulting from a combined sanitary and storm flow collection system.

The liquid treatment facilities at the Norwich WWTF include screening, grit removal, primary treatment, conventional activated sludge designed for carbonaceous-only secondary treatment, and chlorine disinfection. As shown on Figure 21, there is room at the Norwich facility to construct additional aeration basins to the north and east of the existing units, and room for a new secondary clarifier to the east of the largest existing unit.

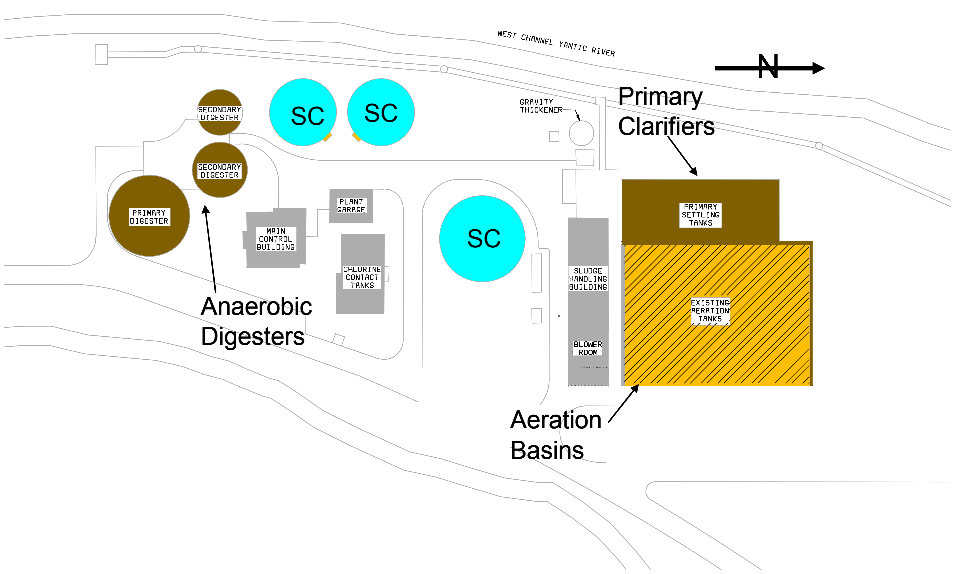

Figure 21 - Norwich Wastewater Treatment Facility

Two treatment alternatives were selected for further development following a technology prescreening exercise: conventional activated sludge, and IFAS. The conventional activated sludge alternative is based on a two-stage nitrification/denitrification process that requires two additional aeration basins of equal size to the existing two, and an additional 120-foot diameter secondary clarifier. For the IFAS alternative, the existing aeration basins would be modified to IFAS reactors in a two-stage nitrification/denitrification configuration with the oxic zone having a media fill fraction of 60 percent. The IFAS alternative also includes a new 120-foot secondary clarifier.

The Norwich facility planning study recommended that conventional activated sludge be implemented for the Norwich plant expansion and upgrade project. The economic evaluation developed during the study was further analyzed to determine how variability in construction costs and IFAS media costs would affect the results of the life cycle cost analysis. The result of the Norwich construction cost sensitivity analysis is shown on Figure 22. At the time of the study, the US average BCI was 3700 and the project cost for conventional activated sludge was estimated at $2.5M lower than the IFAS alternative project cost. The project costs for the two alternatives become closer as the BCI is increased, and are projected to be equivalent at a BCI of approximately 5800.

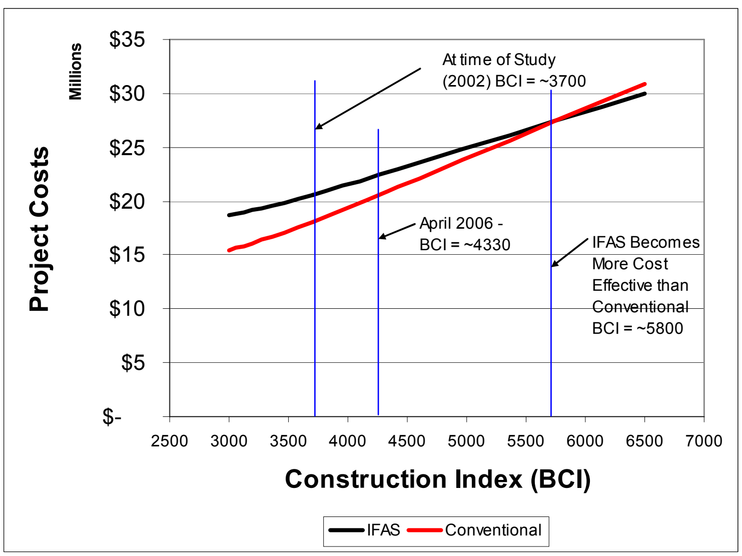

Figure 22 – Norwich Construction Cost Sensitivity Analysis

The result of the Norwich media cost sensitivity analysis is shown on Figure 23. When the Norwich expansion alternatives were in development in 2002, the IFAS media cost was estimated at approximately $16/cf. As shown on Figure 23, the project cost for the IFAS alternative is predicted to be equivalent to conventional activated sludge at a media cost of approximately $10/cf.

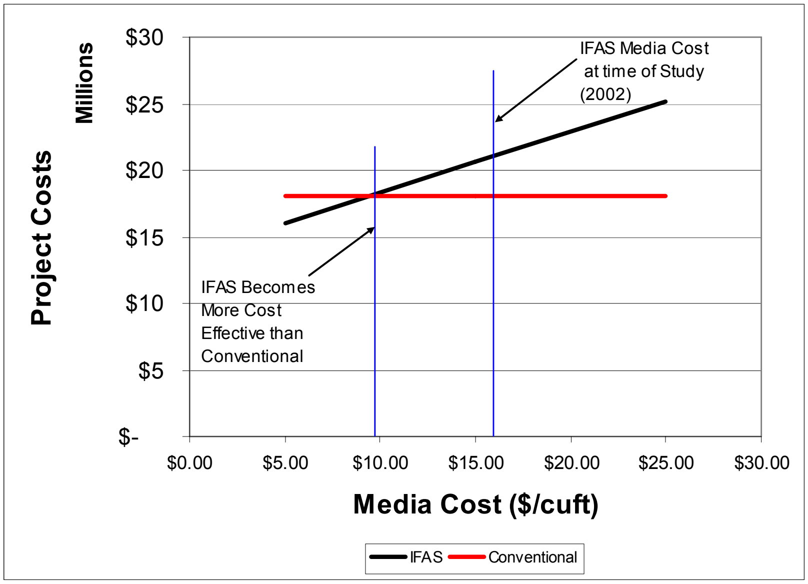

Figure 23 – Norwich IFAS Media Cost Sensitivity Analysis

The Norwich economic evaluation supported the original recommendation for conventional activated sludge, although a $2.5M cost differential represents a savings of only 12 percent, which for study level cost estimating is typically not considered to be significant. Other factors were considered in the decision to stay with conventional activated sludge. Norwich did not have physical site constraints that required the use of a small footprint technology. The process reliability and maintenance requirements for IFAS were also not as well defined in 2002 as they are today. For these reasons, and the fact that there was not an economic incentive for selecting IFAS, conventional activated sludge was the appropriate choice for Norwich at the time. However, IFAS may become a more economical choice for Norwich if construction costs continue to increase and/or IFAS media prices are reduced.

SUMMARY/CONCLUSIONS

There are many cost and non-cost factors that must be carefully considered to determine if IFAS is the right choice for a plant expansion or upgrade project. These factors generally address issues related to treatment concept appropriateness, operational objectives, or design considerations. IFAS is often found to be an appropriate treatment strategy when there are site constraints or restrictions that limit the ability to construct additional process units, when a robust system is needed to increase overall process reliability, or when it is necessary to meet very stringent ammonia and total nitrogen limits. If these are not overwhelming factors, the question of whether IFAS is the right choice often comes back to the economics between IFAS and other viable treatment technologies.

The results of the sensitivity analyses discussed in this paper identified four key factors that have a high influence on the economic viability of IFAS including plant size, land value, IFAS media costs, and construction costs. For the hypothetical example presented in this paper, IFAS was found to be more cost-competitive with conventional activated sludge and step-feed at plant sizes of less than 15 to 20 mgd, and generally more economical than the MBR and BAF technologies for all plant sizes. It was also found that IFAS had an economic advantage over conventional activated sludge when the land value was above approximately $1.75M/acre and when IFAS media costs were below $10/cf. Finally, IFAS became very cost-competitive with conventional activated sludge when the construction costs were elevated and the BCI was above approximately 5800.

ACKNOWLEDGMENTS

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Cost References

Energy cost information is available at the US Energy Information Administration (EIA) website: http://www.eia.doe.gov/
Construction material costs are available from the US Bureau of Labor and Statistics (BLS), producer price index (PPI) website: http://www.bls.gov/ppi/home.htm
The Building Cost Index (BCI) is formulated by the Engineering News Record (ENR) and can be accessed from their website: http://www.enr.com (historical data is available to subscribers only).