"Economics of Wastewater/Biosolids Treatment by E-Beam"

Combining Science and Technology
To Protect and Conserve Our Environment

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Laboratories for Engineered Environmental Solutions

mission green

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NSF Workshop on Application of Electron Beam (E-Beam) Technology on Wastewater and Biosolids Management
Fermi National Accelerator Laboratory, Batavia, IL ▫ May 10-11, 2018

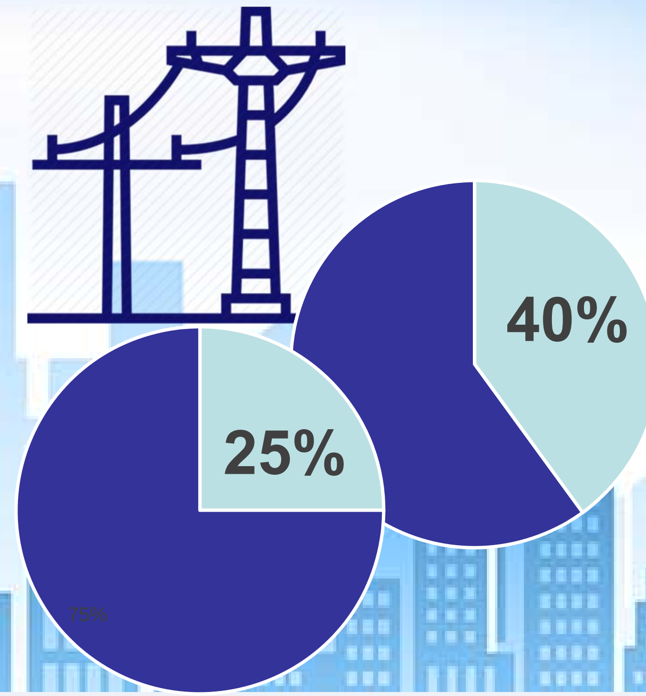
http://labees.civil.fau.edu

Scale

- About 15,000 WWTPs in the US
  - About 500 facilities treat 10 – 100 MGD

40 BGD Wastewater

7 MDTPD Biosolids



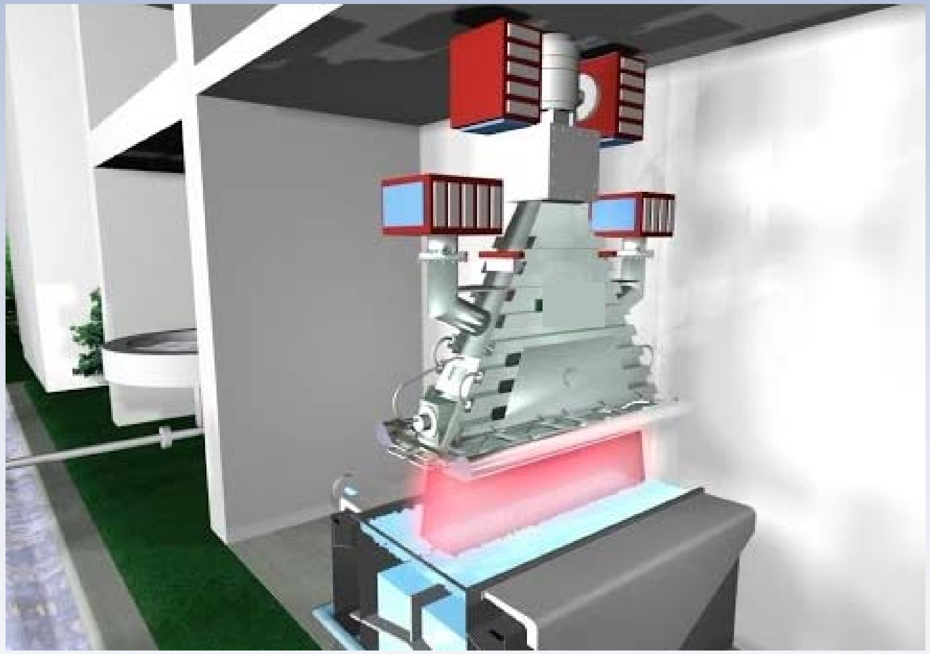
25-40% of WWTP Budgets are for Electricity

Target Applications

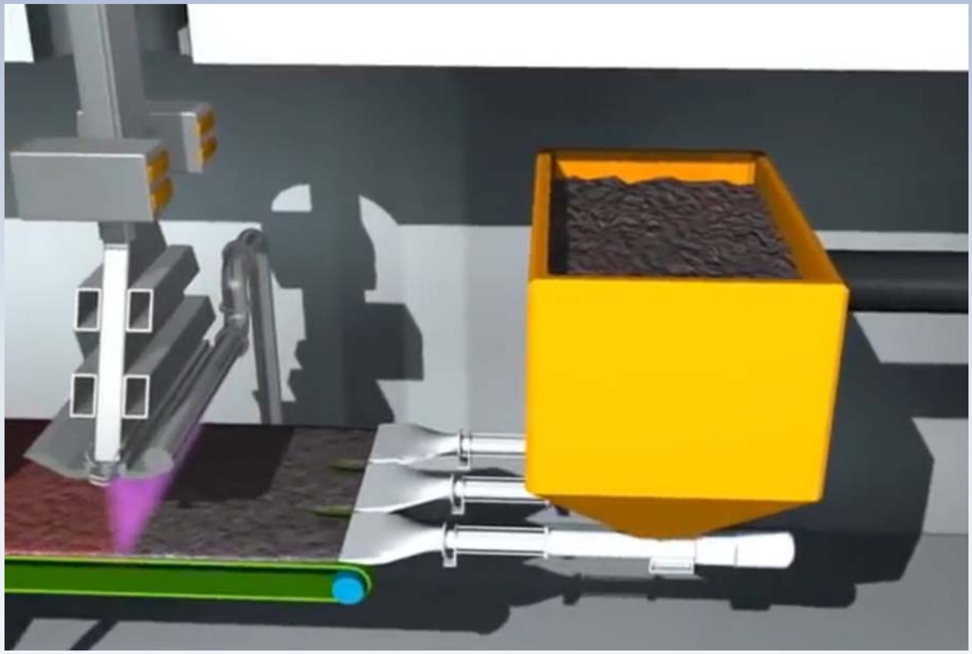
Wastewater Treatment | **Biosolids Treatment**

Target Applications

Wastewater Treatment



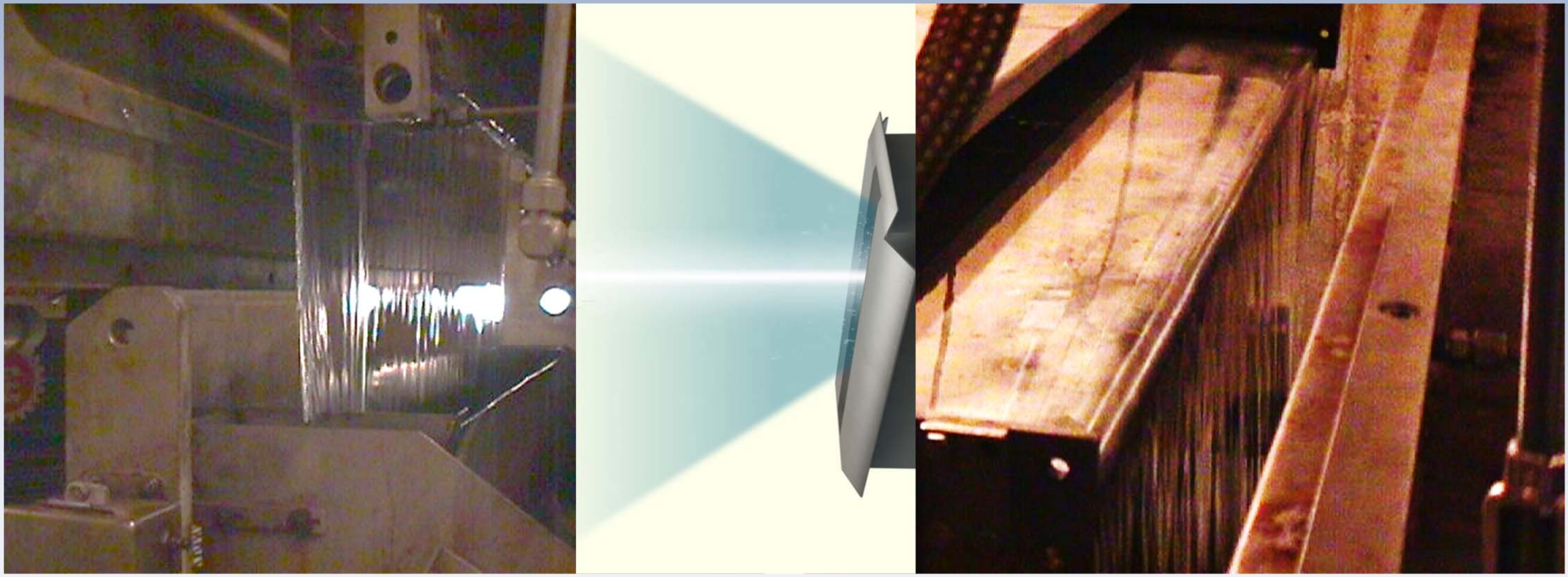
Biosolids Treatment



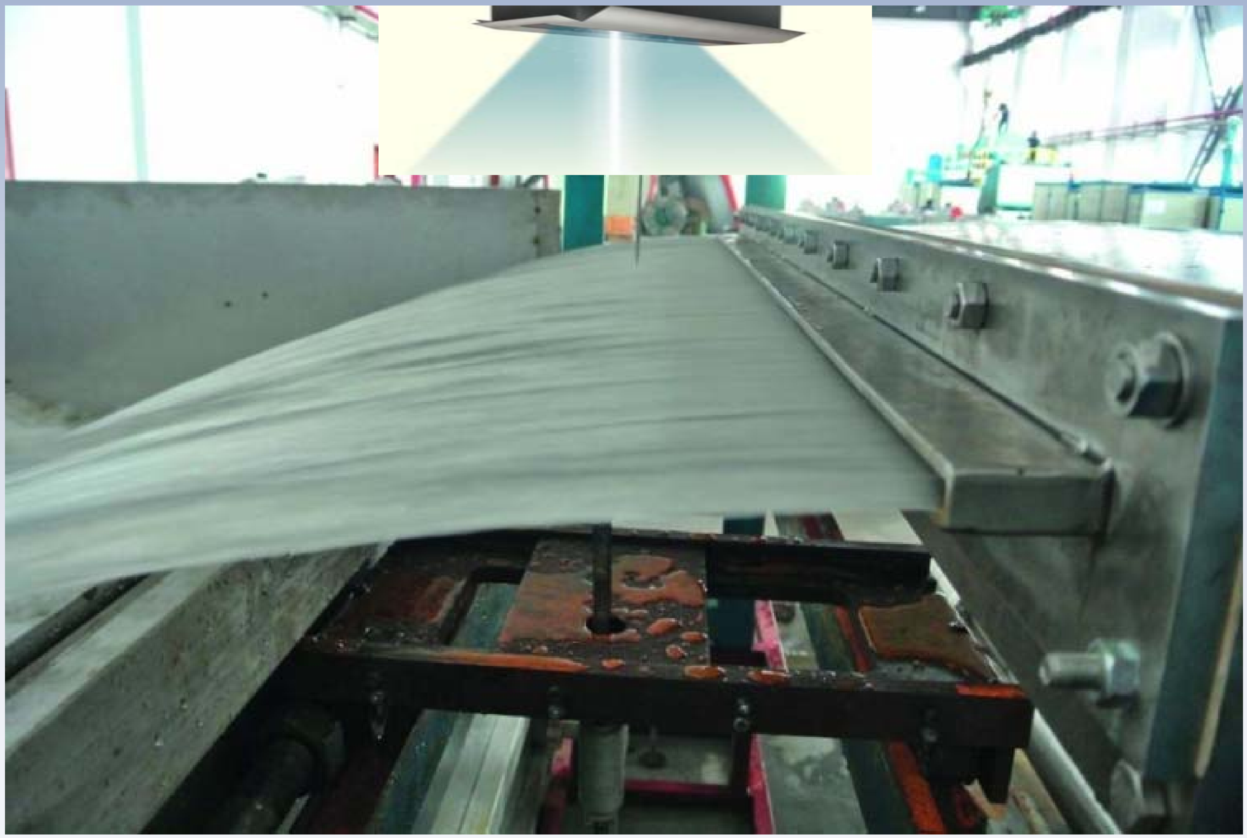
Virginia Key EBRF

- **Specifications:**
  - **1.5 MeV, 75 kW, 8.3 kGy @ 100 – 150 gpm**

Horizontal Configuration



Vertical Configuration



Previous Biosolids Research

- Sludge conditioning, digester performance, dewatering and disinfection
- 3-20 kGy showed enhanced conditioning, digestion improvements and better dewatering characteristics, but effects were not linear
- E-beam reduced pre-digestion dewatering requirements, polymer usage, and final hauling/disposal costs

Radiation-Assisted Process Enhancement in Wastewater Treatment

Daniel E. Meeroff[1]; Thomas D. Waite, P.E., M.ASCE[2]; Junko Kazumi[3]; and Charles N. Kurucz[4]

Abstract: Laboratory and pilot tests were conducted to investigate the use of ionizing radiation at an activated sludge wastewater treatment facility with residuals processing. Operational enhancements were investigated with respect to bulking control, thickening enhancement, and anaerobic stabilization processes. Radiation caused permanent effects in measured sludge parameters including solids content, chemical oxygen demand, ammonia-nitrogen, zeta potential, specific surface area, resistance to filtration, sludge volume index, pH, organic acid production, and digester gas evolution. Analysis of beneficial effects from preliminary studies and pilot tests demonstrated that a dose of 2–3 kGy would be potentially successful for bulking control and to a lesser degree, enhanced thickening and radiation-assisted anaerobic digestion. A cost analysis based on preliminary tests determined that a centralized electron beam irradiator could be applied economically in an integrated approach at an estimated annual savings of $0.2–2.7 million depending upon the application. Considering that the annual cost of operating an accelerator unit was estimated at $2.4 million ($2.16/m^3), this might translate into an important savings for a large-scale wastewater treatment facility.

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CE Database subject headings: Activated sludge; Sewage treatment; Anaerobic digestion; Wastewater treatment; Radiation; Laboratory tests.

Introduction

The performance of activated sludge wastewater treatment and sludge management systems is limited by the maximum operational efficiency of the unit processes, most of which have not changed substantially in the last several decades. Operational problems that inhibit treatment performance will hinder the ability to deal with expected increased loading in the future. In the United States, more than $2 billion is spent annually treating and managing approximately 5–7 million tonnes of biosolids from over 13,000 publicly owned treatment works (POTWs) (Ponugoti et al. 1997). Solids handling costs constitute a considerable portion (up to 50–60%) of the operating budget of a typical wastewater treatment plant (Evans 1989) and have been steadily increasing as more stringent regulations governing biosolids disposal practices are promulgated (Balm'er 1994). These economic factors combined with mounting pressures from population growth and changing regulations will challenge existing POTWs to plan for the future. A cost effective approach would include ways to reduce sludge production and facilitate sludge processing while simultaneously improving operation and increasing unit process loading rates. Clearly, any process, which can reliably improve the efficiency of existing wastewater treatment processes will have an economically significant cost savings potential. In this research, an integrated approach utilizing ionizing radiation in a multipurpose wastewater treatment and sludge management application was investigated.

Ionizing radiation was selected because of its potential to provide multiple benefits with regard to wastewater treatment and sludge management. At doses from 2–6 kGy, irradiation has been used successfully to achieve a variety of treatment objectives, including toxic chemical destruction (Cooper et al. 1992; Kurucz et al. 1995), flue gas treatment (Frank 1995), heavy metals immobilization and partitioning (Chaychian et al. 1997), and pathogen inactivation (Suess and Kessel 1977; Waite et al. 1997; Sedlácek 1985; Maloof 1988; Cooper et al. 1992). It has also been demonstrated that ionizing radiation can alter the physical properties of wastewater sludge particles to enhance dewaterability and biodegradability through the action of radiation-induced free radical chemistry (Etzel et al. 1969; Sedlácek et al. 1985; Kurucz et al. 1991; Wang 1993; Waite et al. 1997). The ability of ionizing radiation to compete with chemical treatment based on performance standards is acknowledged, and economic analyses confirm that radiation techniques for waste treatment are competitive with existing advanced treatment technologies (Maloof 1988; McKeown 1996).

The use of irradiation as a multipurpose treatment tool within a wastewater treatment facility has the potential to beneficially impact several aspects of operation. For instance, the ability of irradiation to eliminate toxic chemicals and break down recalcitrant organics is well known, therefore, it is expected that irradiation will (1) facilitate biodegradation, (2) enhance sedimentation

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Note. Associate Editor: Mark J. Rood. Discussion open until July 1, 2004. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on June 19, 2002; approved on April 24, 2003. This paper is part of the ***Journal of Environmental Engineering***, Vol. 130, No. 2, February 1, 2004. ©ASCE, ISSN 0733-9372/2004/2-155–166/$18.00.

DOE Workshop

- DOE hosted the “Workshop on Energy and Environmental Applications of Accelerators” (2015)
  - Identified barriers to commercialization of electron beam technology for environmental applications
  - “For the technology to be used at a large scale, high-power electron beam systems (>1 MW, >1 MeV) will need to be developed”

Preliminary Cost Analysis Specifications

- First estimate hypothetical number of units
- Assumptions:
  - P = 1.0 MW (per DOE Workshop)
  - D = 20 kGy to achieve disinfection + organics mineralization + biosolids enhancements
  - Efficiency (η) = 42-75%
- Solve for Q = 0.46 – 0.86 MGD
- This means many units (*n* = 12 – 22) are needed to treat the full flow for a 10 MGD rated facility

$$P = \frac{QD}{\eta}$$

Disclaimer

- The data presented here are based on a hypothetical situation and do not represent the views of the presenter, the institution, or any vendor or utility
  - Based on literature, the 20 kGy dose has additional benefits beyond disinfection
  - But if the dose is 2 kGy, then the power and capital costs are reduced by a factor of 10
  - Other scenarios can be run with this cost model
  - No cost savings from reducing polymer demand or increasing methane yield were input into the model

Capital Cost Assumptions

Wastewater Treatment

- Q = 10 – 50 MGD
- 1-MW, 1-MeV, 20 kGy
- $2 per Watt
- 4% interest, 15 yr lifetime
- 78% beam power efficiency
- 75% wall power efficiency

Biosolids Treatment

- Q = 8 – 40 DTPD
- 1-MW, 1-MeV, 20 kGy
- $10 per Watt
- 4% interest, 15 yr lifetime
- 78% beam power efficiency
- 75% wall power efficiency

O&M Cost Assumptions

Wastewater Treatment

- Two Class A operators @ $25/hr
- 29% fringe
- 24 hr/d, 365 d/yr
- $0.07/kWh
- Water consumption = negligible
- Maintenance = 2.5%Capital

Biosolids Treatment

- Two Class A operators @ $25/hr
- 29% fringe
- 16 hr/d, 20 d/month, 12 month/yr
- $0.07/kWh
- Water consumption = negligible
- Maintenance = 5%Capital

Targets for Comparison

Wastewater
$2 – 4/kgal

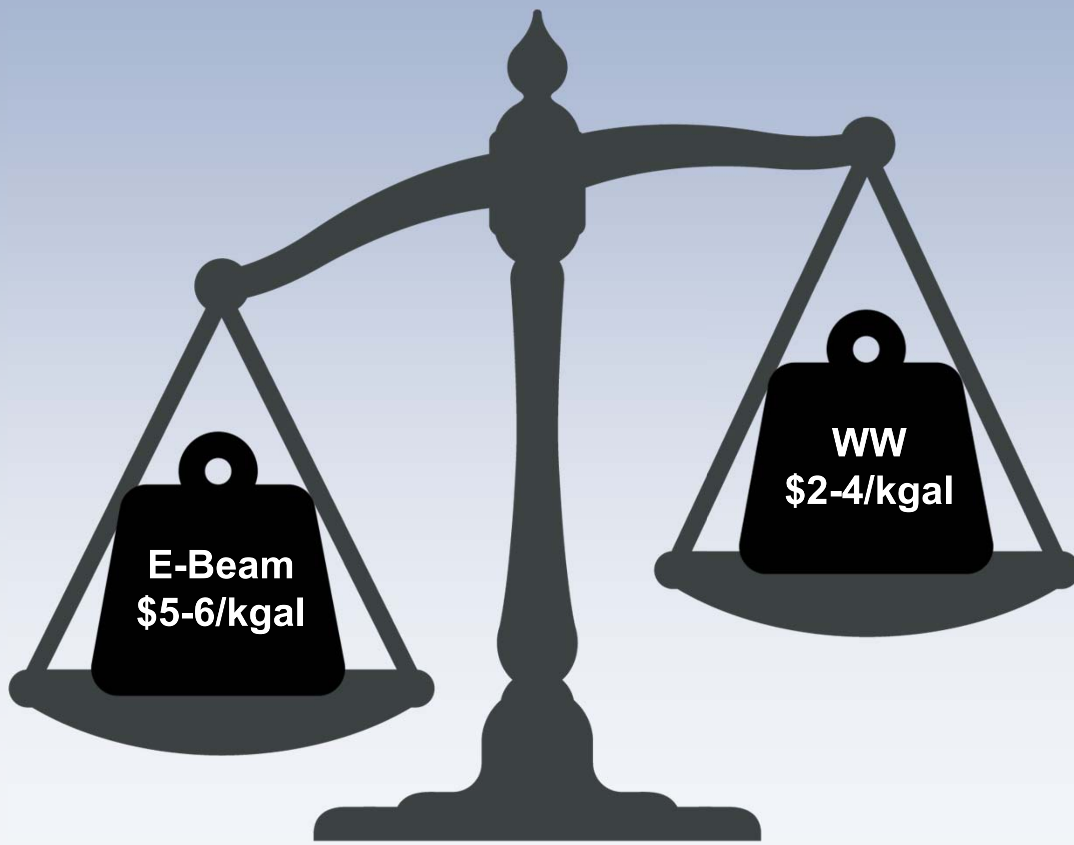
Biosolids
$60 – 90 DTPD

Cost Breakdown: WW

	10 MGD	50 MGD
Unit Cost (U) $2 per Watt	$44.1M	$220.7M
No. Units 1-MW + 1 spare	**24**	**112**
Control Sys. 5%U	$2.2M	$11.0M
Installation 7.5%U	$3.3M	$16.5M
Shielding 10%U	$4.4M	$22.1M
Mechanical 2%U	$0.9M	$4.4M
TOTAL	$54.9M	$274.7M
(A,4%,15)	$4.9M	$24.7M

	10 MGD	50 MGD
Unit Cost (U) $2 per Watt	$44.1M	$220.7M
Labor 2 @ $25/hr + 29% fringe	$0.6M	$0.6M
Electricity $0.07/kWh	$13.5M	$75.1M
Maintenance 2.5%U	$1.4M	$6.9M
TOTAL O&M	$15.5M	$138.7M
TOTAL Annual Cost	$20.4M	$99.8M
$/kgal	**$5.59**	**$5.47**

Wastewater Cost$



Cost Breakdown: Biosolids

	8 DTPD	40 DTPD
Unit Cost (U) $2 per Watt	$1.2M	$6.0M
No. Units 1-MW + 1 spare	2	2
Control Sys. 15%U	$0.2M	$0.9M
Installation 25%U	$0.3M	$1.5M
Shielding 40%U	$0.5M	$2.4M
Mechanical 35%U	$0.4M	$2.1M
TOTAL	$2.62M	$12.9M
(A,4%,15)	$0.23M	$1.16M

	8 DTPD	40 DTPD
Unit Cost (U) $2 per Watt	$1.2M	$6.0M
Labor 2 @ $25/hr + 29% fringe	$0.25M	$0.25M
Electricity $0.07/kWh	$0.07M	$0.37M
Maintenance 5%U	$0.13M	$0.64M
TOTAL O&M	$0.45M	$1.26M
TOTAL Annual Cost	$0.68M	$2.42M
$/DT	**$233**	**$166**

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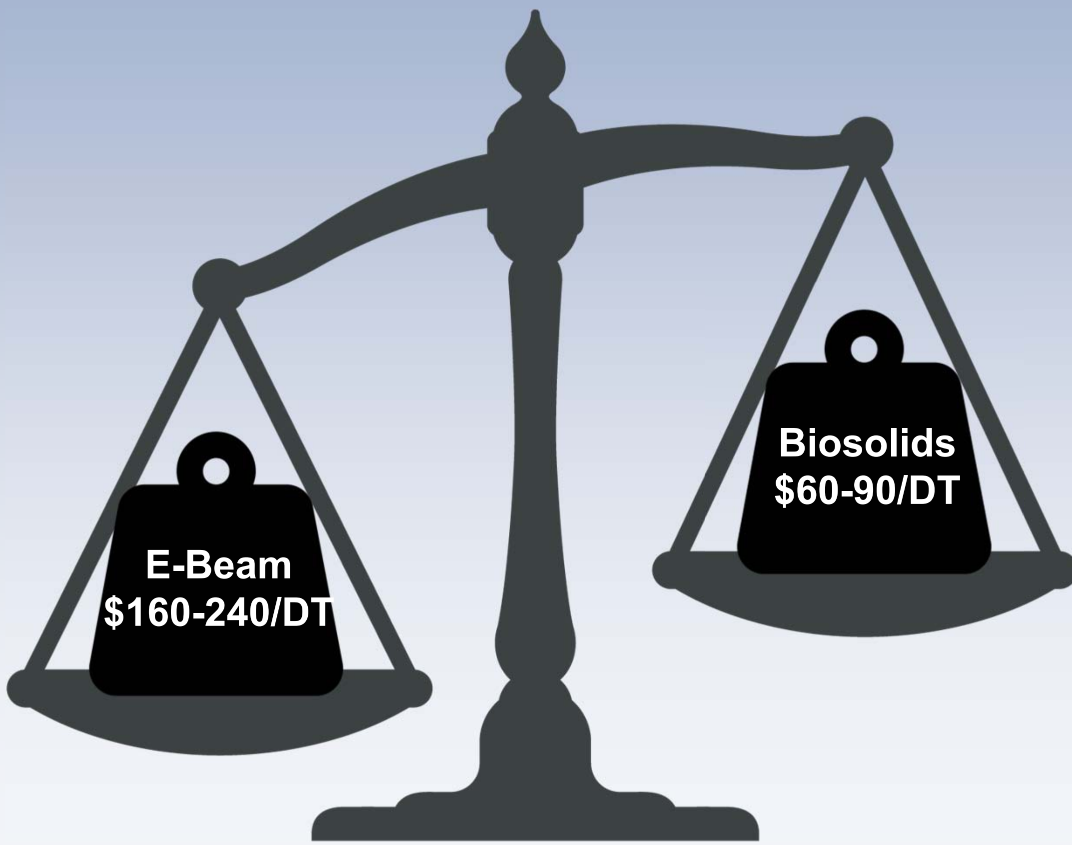
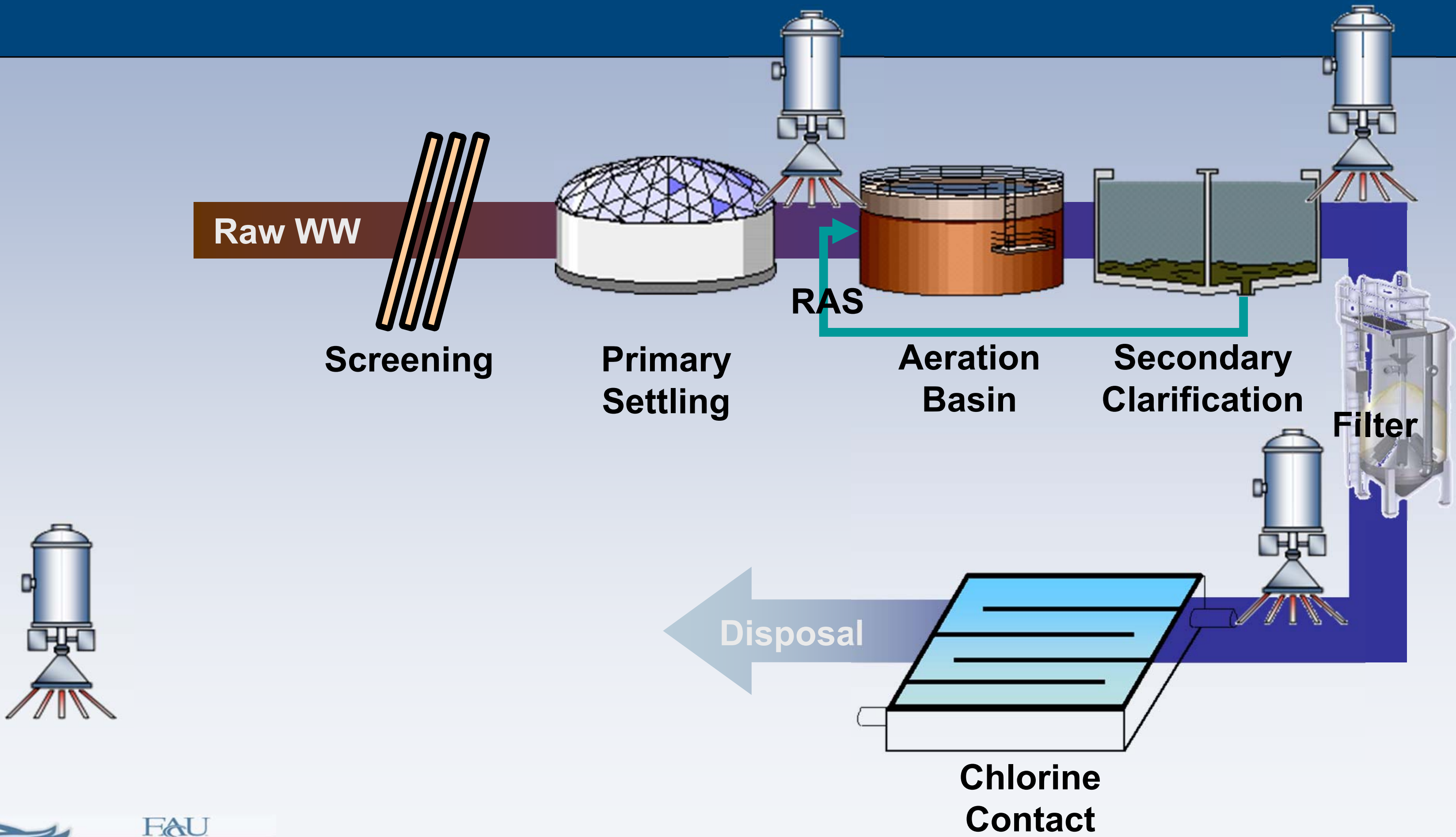
Biosolids Cost$



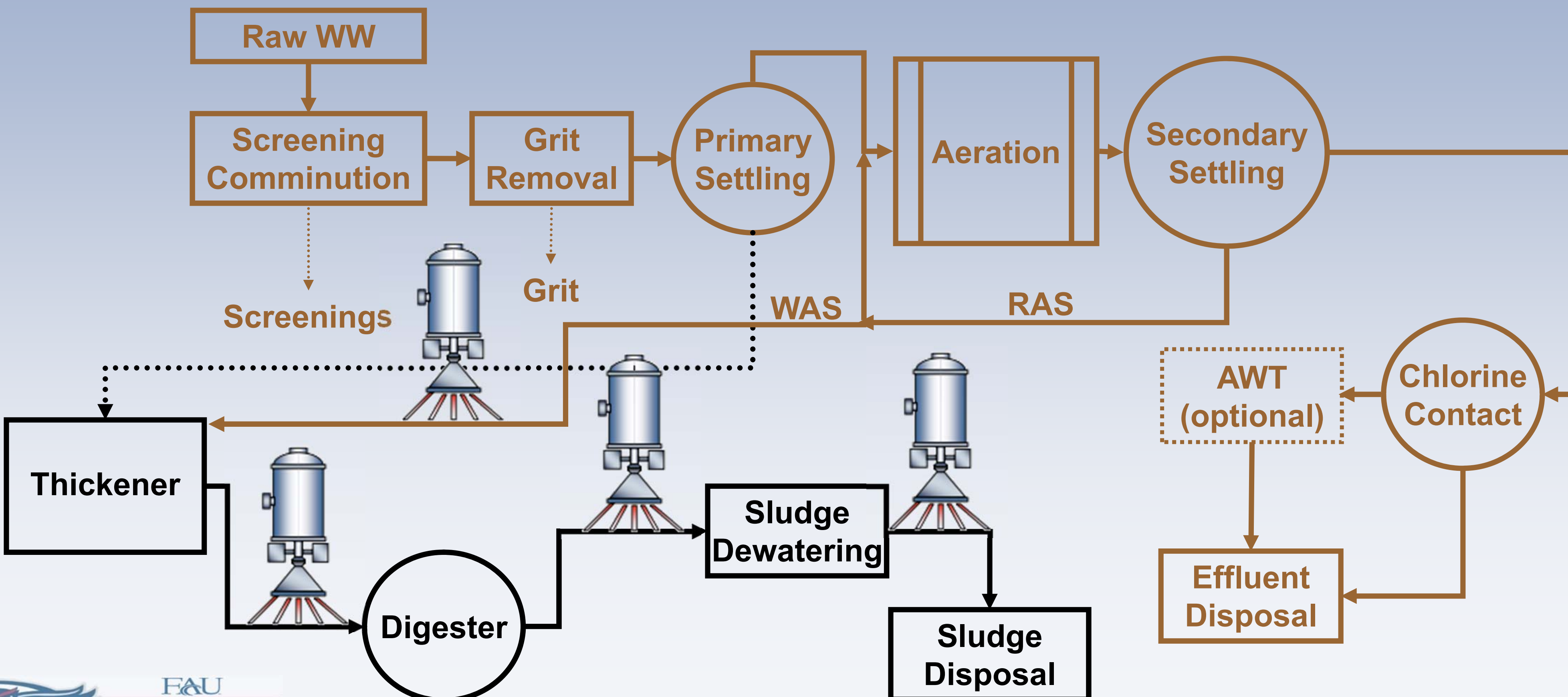
Don't Give Up Just Yet

- So we just missed the target with these hypothetical scenarios
  - WW has diurnal flow variations and variable quality
  - Biosolids lends itself to batch processing
- So let's ask some questions:
- Where in the train is treatment most effective with no adverse impacts to downstream processes?

WW Process Train



Biosolids Process Train



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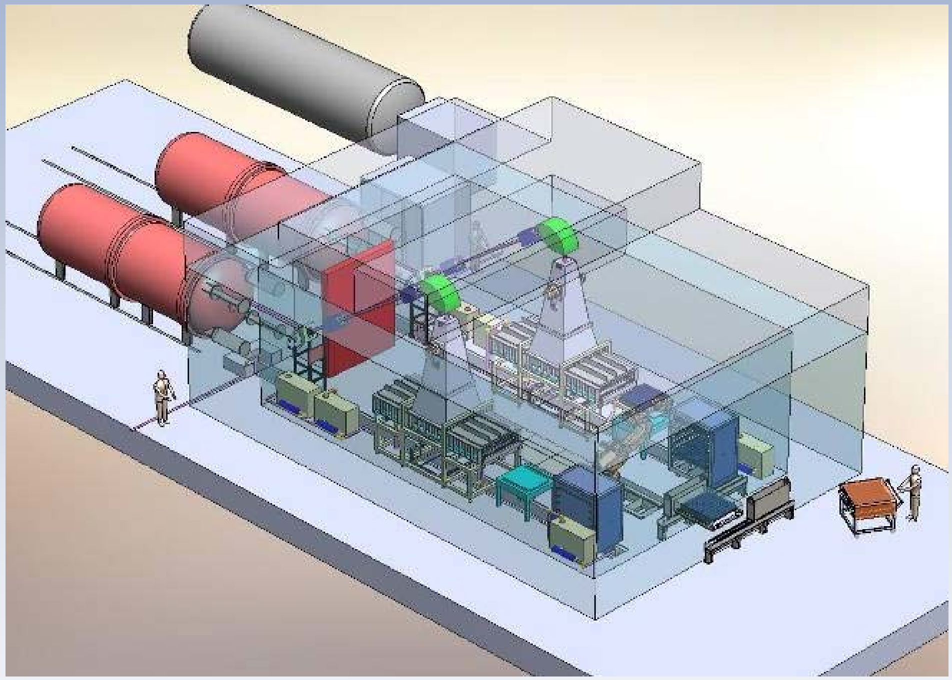
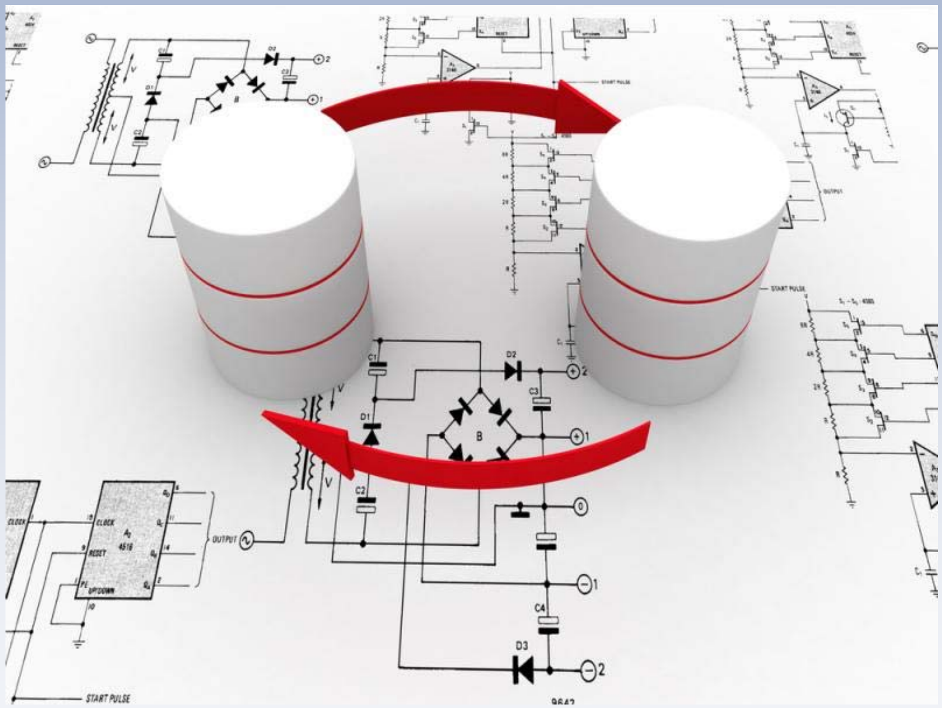
More Questions

- How to deliver the right dose at the right location?
  - Conveyor belts, horizontal or vertical configuration
- What is the best way to provide the redundancy?
  - Is it useful to treat a percentage of the flow with bypass?
  - If modular, is the design to have multiple flow streams irradiated by individual beams or the opposite?



Reliability & Redundancy

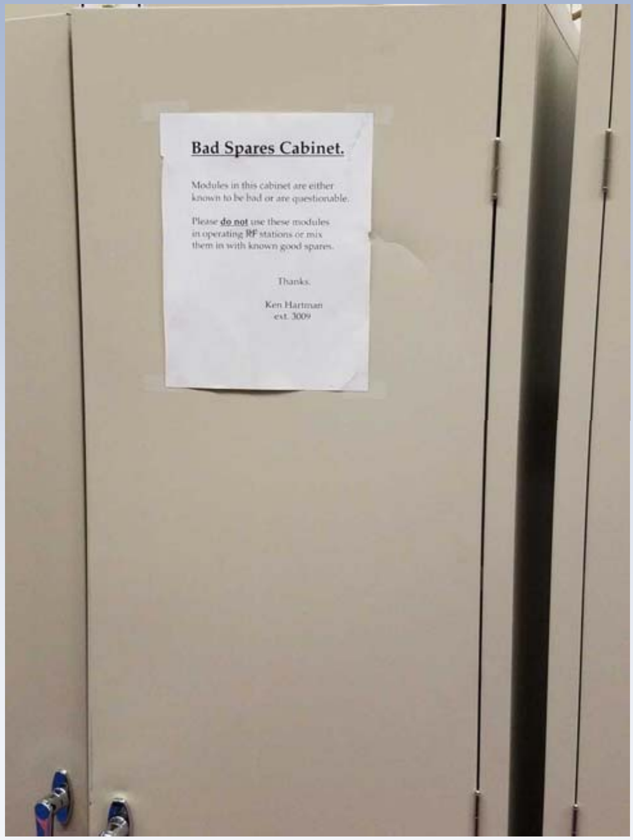


- Rules require the process to operate for 100% of the design flow with the largest unit out of service
  - Spare unit (alternate)
  - Bypass
  - Sufficient on-site storage to manage MTBF*

*Mean Time Between Failures

Reliable Backup

- Multiple, fully independent modules with hot start spare units
  - Electricity cost for standby
- What is the warmup time to reach full power?
- Flow pacing
- Reduce downtime and repair time
- What components tend to fail?



Backup Power

- **When switching to generator power, how does that affect the beam quality and treatment performance?**

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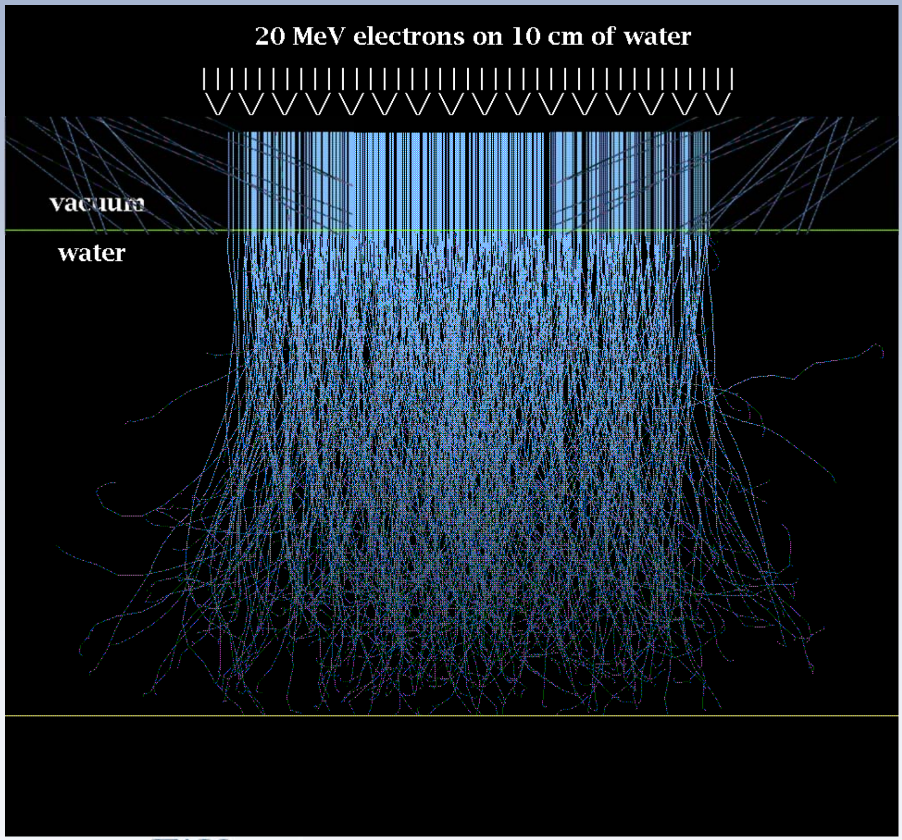
Fouling/Ageing

Wastewater/Biosolids + high energy electrons can be a harsh environment

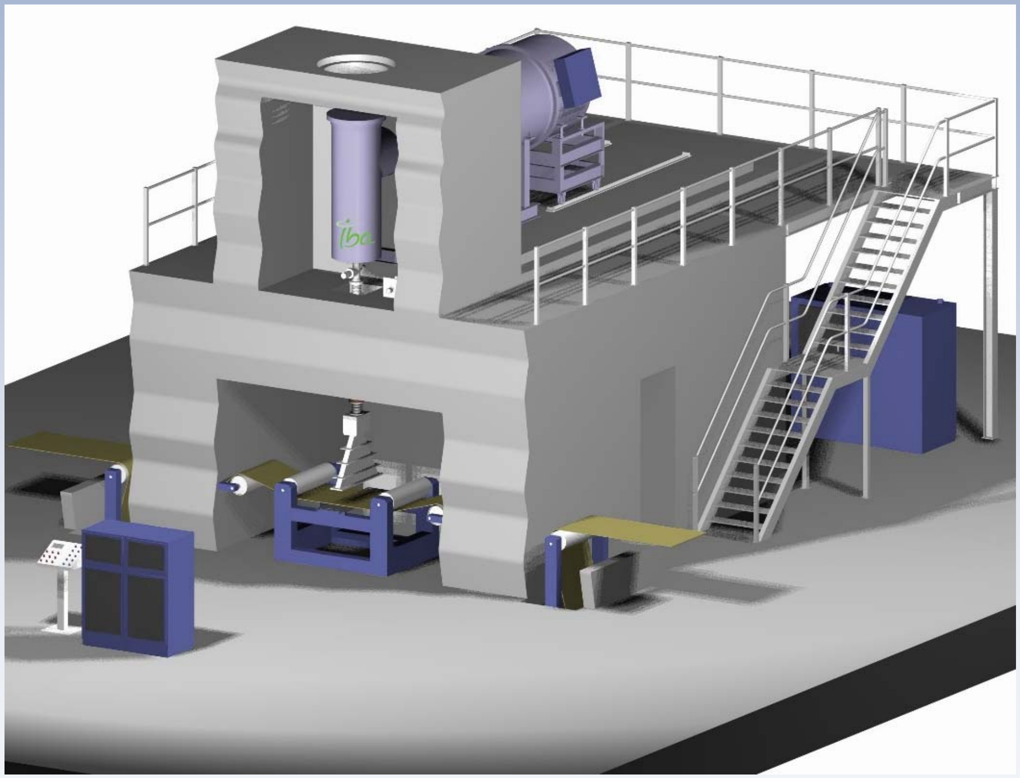
Opportunities for Innovation

Hydraulics



- Optimize beam to target efficiency
  - Reduce backscatter, stray electrons, radical scavenging
- Uniform flow distribution in thin film
  - Minimize splashing/spray of corrosive material
  - Minimize air entrainment
  - Minimize/manage distributor fouling and losses

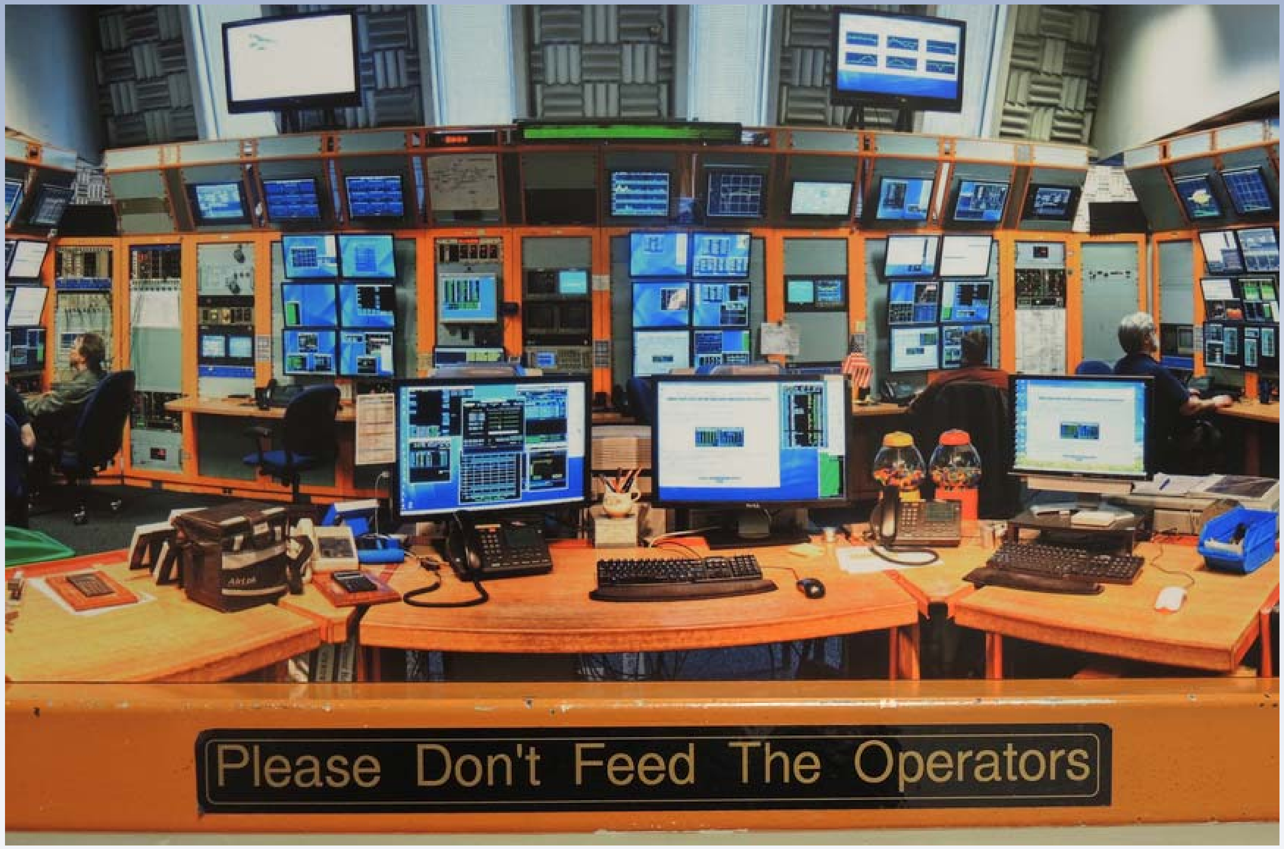
Shielding



- **Minimize shielding requirements**
- **Minimize footprint to lower capital costs**

Monitoring

- Machine protection
- Personnel protection
- Beam quality
- Beam energy
- Beam loss
- Dose uniformity
- Dose verification
- Runtime
- Film thickness



More Thoughts for Later

- Smart control systems with remote diagnostic sensors
- Reduce footprint but allow for routine maintenance without disrupting treatment
  - Accelerator vaults must be easily accessible for maintenance, shielded and interlocked to allow safe servicing while other modules are in full operation
- New cryocooled SRF high energy units can reduce the number needed to process large flows
- Can we get the cost to below $1/W?
- Can we reduce the power consumption?

The Road Ahead

- Test new accelerators using the LIFT program
  - Target large sized facility but <1% of the flow
  - Create competition (Ebeam Prize)
- Ideal concept for ebeam supplier may have to be Design, Build, Operate (and Insure)
- Form a group to write the electron beam chapter in Metcalf & Eddy textbook

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