The Industrial Energy Manager’s Essential Tool Kit

Energy Managers’ Workshop
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Outline

- Background
- Technical Approach
- Portfolio of Tools and Techniques
- Case Study (Lagniappe)
Industrial Processes – Inputs and Outputs

**Utility System**
- **FUEL**
- **ELEC**

**MFG Process**
- **RAW MAT**
- **PRODUCTS**

**Waste Treatment**
- **ENERGY**
- **EFFLUENT DISCHARGE**

**Controllable Parameters**
- Raw Mat Yields
- Reaction Kinetics
- Unit Operations
- Recycle Points & Rates
- Energy Consumption

**Process Mods**
- Heat Recovery
- Power Reduction
- Optimize CHP

Impact on Profits

<table>
<thead>
<tr>
<th></th>
<th>Throughput or Capacity</th>
<th>Waste Treatment</th>
<th>Energy Cost</th>
<th>GHG Emissions</th>
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<tbody>
<tr>
<td>Yield + Kinetics</td>
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<tr>
<td>Unit Operations</td>
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<tr>
<td>Optimum Recycle</td>
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<tr>
<td>Energy Eff (Usage)</td>
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<td>←</td>
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<tr>
<td>Energy Eff (Supply)</td>
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<td>←</td>
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</table>
Ideally, we should consider both Process and Energy on Integrated Basis

- **PROCESS MODIFICATIONS**
  - Potentially Huge Impact, but Higher Cap Cost + some Potential Risk

- **ENERGY EFFICIENCY OPTIMIZATION**
  - Smaller Impact, but Lower Cap Costs & Almost Zero Risk

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**Process Engineer’s Viewpoint**

**PARADIGM:** Utilities available instantaneously at **ZERO** cost

**RESULT:** Waste Energy in both Process & CHP System
Utility Engineer’s Viewpoint

**PARADIGM:** Must supply demand at **ANY** Cost  
**RESULT:** High Flexibility, Low Efficiency

Integrated Optimization Viewpoint

- Energy
- Emissions
- Capacity

**Economics**

**Process**

**Energy Utilities**
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Process Energy Optimization (PEO)

Using Energy Analysis (fuel + power) to identify and exploit profitable opportunities for process efficiency improvement
PEO Integrates Process and Utilities

A “high level” view of the Process and Utility Systems

Energy Supply, Conversion, & Distribution Systems

Chemical Plant “Processing” Steps (see PFD)

Finished Chemical Products

Waste Collection, Reduction, Recovery, & Discharge

“We had never suspected that using energy differently can improve the process”.
David Broad, Site Mgr. BASF

PEO looks at the Process and Utility Systems as a single Unified System

The Business Unit

G&A and Selling Expenses

Labor

Other

Energy

Raw Materials

Scrap

Profit

Optimization links ?

PEO uses Financial and Technical Models to directly link Engineering w/ Economics

An Engineering Model

A Financial Model

Optimization Links—“X% What ifs”: What is the annual K$/yr saving from a 1% or 10% annual improvement in product output, yields, quality, maintenance effectiveness, operator productivity and energy performance?
PEO Methodology

- Documentation - process & econ. models
- Correct product/waste & utility pricing
- Identify major $ impacts on Bottom Line, using sensitivity analysis (What If?)
- Focus on Critical Cost Issues (CCIs)
- 3-phase approach
  - Level 1 – rules of thumb, ball park economics
  - Level 2 – prelim calculations, conceptual design
  - Level 3 – detailed calcs, vendor quotes

PEO – Key Features

- Integrated holistic analysis
- 3-phase approach (increasing levels of effort and accuracy)
- Collaborative Effort → Consultant plays “coach/facilitator” role at Level 1; Team member at Level 2
- Immediate Results
- Implementation Road Map
- Thorough documentation
- Plant Ownership and Accountability (KPIs)

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Technical Tool Kit

- "COST FLOW" DIAGRAMS for CCIs
- STRUCTURED BRAIN-STORMING

- PFDs and HMB SIMULATION MODELS
- OPERATIONAL IMPROVEMENTS
- EQUIPMENT UPGRADES
- PROCESS INTEGRATION (Pinch Analysis)
  - PROCESS MODS – higher capacity & yields, less waste
  - OPTIMIZED HEAT RECOVERY
  - OPTIMIZED CHP STRUCTURE
- PERFORMANCE MONITORING

Level 1

Levels 2 & 3
Example of 1-line Cost Flow Diagram

Utilities: Major Chemical Plant site, Texas

Utilities

CrITICAL COST ISSUES

- Steam
- Electricity
- Natural Gas
- Cooling Water
- Wastewater Treatment
- Incineration
- Compressed Air
- Treated Water
- Nitrogen

Utilities

- #1 $1,131 k/yr 9.9% 30k KESV $5.51/KESV
- #2 $6,647 k/yr 55.0% 10.244k kgal $0.041/kgal
- #3 $3,487 k/yr 29.3% 590k MBtu $0.041/MBtu
- #4 $420k/yr 3.5% 10.244k kgal $0.041/kgal
- #5 $11,900k/year EC TEX PE-1 Utilities
- #6 $44.4/MWh
- #7 $3,487k/yr 29.3% 150k MWh $5.91/MWh
- #8 $420k/yr 3.5% 10.244k kgal $0.041/kgal
- #9 $74k/yr 0.6% 3k lb $23.06/klb
- #10 $377k/yr 3.5% 10.244k kcf $0.174/kcf

Structured Brainstorming w/ Stakeholders

Site Participants Include:
- Site & Mfg. Unit Mgmt.
- Raw Matls./Interm. Supplier
- Process Tech. Experts
- Maintenance Specialist

Totals: 6-10 Plant, plus 5-7 Consultant team

Involves Key People on an ‘AS NEEDED’ basis: Only One Week per Mfg. Dept.
## Summary of Level 1 study

<table>
<thead>
<tr>
<th>Features</th>
<th>Benefits</th>
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</thead>
<tbody>
<tr>
<td>Integrates Process and Energy</td>
<td>Lowers Unit Cost of Finished Product</td>
</tr>
<tr>
<td>Involves Your Key People</td>
<td>Doable Solutions, Commit to Implement</td>
</tr>
<tr>
<td>Focuses on Critical Cost Issues</td>
<td>Saves Time, Maximizes Results</td>
</tr>
<tr>
<td>Uses Financial &amp; Technical Tools</td>
<td>Identifies Most Valuable Solutions</td>
</tr>
<tr>
<td>Creates Immediate $$ Results</td>
<td>Jump Starts Program, Instant Credibility</td>
</tr>
<tr>
<td>User Friendly Reports</td>
<td>Quickly Present and Implement Solutions</td>
</tr>
</tbody>
</table>

## Technical Tool Kit

- “COST FLOW” DIAGRAMS for CCIs
- STRUCTURED BRAIN-STORMING
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Heat and Material Balance Simulation Models (Process + Utilities)

- Essential to get full understanding of how the Raw Materials and Energy are used
- Helps to pin-point areas of opportunity
- Suggests potential process improvements
- Essential design basis for Level 2 Energy Optimization study (process heat recovery as well as CHP system)

Example PFD: Bio-process plant
### Example HMB model – biotech plant

#### Material and Heat Balance (approximate)

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<th>Material</th>
<th>MW</th>
<th>Stream 1</th>
<th>Stream 2</th>
<th>Stream 3</th>
<th>Stream 4</th>
<th>Stream 5</th>
<th>Stream 6</th>
<th>Steam</th>
<th>Condensate</th>
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#### Stream num...

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</tbody>
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### CHP System Simulation Model

#### CHP System Simulation Model

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Marginal steam prices - discontinuous

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Levels 1

Levels 2 & 3
**Operational Improvements**

Energy Cost savings can be achieved at little or no capital cost through:

- Following industry Best Practices
- Reducing Process variability
- Flowsheet Improvements via simple process piping/control modifications
- Optimum equipment load allocation policies
- Performance Monitoring & Targeting
- Process Controls (eg. CHP optimizer, MVC)

**Low-cost Best Practices**

- Minimize running spares
- Avoid keeping equipment on hot standby
- Maintain Steam traps, insulation
- Steam/Air leak detection & repair program
- Cooling water treatment
- Boiler & Furnace O2 controls
- Burner management
- Flue gas stack damper control
- Minimize CW and process fouling
- Optimize HX cleaning schedules/techniques
Benefits of Reducing Process Variability

- Energy savings
- Capacity debottlenecking (throughput)
- Improved product quality
- Improved yield
- Reduced wastes
- Increased profitability

PV = Process Variable (e.g. prod. moisture %)
SP = set point
MV = Manipulated Variable (e.g. steam flow)

Flowsheet Improvements

- Minimize non-isothermal mixing
- Minimize non-isoconcentration mixing
- Minimize range of recycle loops
- Avoid needless heating / cooling / pumping
- Add Degrees of Freedom via piping/control modifications (e.g. bypasses, manifolds)
Examples of Simple Piping mods

Load Management Concepts

- Minimize number of machines being operated in parallel
- Reduce the rate at which individual machines are being run, through minimizing recycle flows
- Operate equipment at near its maximum efficiency point, to the extent possible
- Assign maximum duty to the most efficient equipment (in a parallel set), and use the least efficient equipment as the “swing” machine
- Optimize sparing philosophy (eg. N+1 vs N+2)
- Add Degrees of Freedom as necessary
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Equipment Efficiency Upgrades

- Pumps
- Compressors
- Motors
- Heat Exchangers
- Fired heaters (furnaces)
- Boilers (fired and unfired)
- Steam & Gas Turbines
- Refrigeration cycles

Electronic spreadsheet templates are most convenient
Retrofit selected motors with VSDs

Generally best when:
- HP > 500
- Load < 70%

903 MWh/yr
= $24.4 K/yr
ROI = 17.8%

Pump Networks with and without VFDs

Load Management (pumps on or off as required) + One pump running on VSD (always ON)

Capacity that results in ENERGY LOSSES (CV + Recirc.)

Intermediate scenario of Load Mgmt, where un-needed pumps are turned off, is not shown
**HX modification strategy**

Goal = Move operating point towards Target Zone

![Diagram showing HX modification strategy](image)

**Shell-side Helical Baffles**

Betters Temp Profile and Flow Pattern

![Diagram showing shell-side helical baffles](image)
**Furnace/Boiler Air Preheating**

Flue Gas 100,000 lb/h 700 F

Existing Steam Header

Flue Gas 100,000 lb/h 400 F

Case 1 | Case 2
---|---
Process duty, MW@15 psig | 64.0 | 64.0
Heliodyne duty, MW@15 psig | 9.0 | 9.0
Fuel gas flow, lb/h | 5,000 | 5,000
Fuel Input (HHV), MMBtu/h | 100,000 | 100,000
Overall Efficiency, % | 78.1 | 86.4

**Arbitrage: shifting duty between Utilities**

New steam heaters can provide an additional degree of freedom to shift duty from high-cost hot oil to LP stm.
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How can we reduce Process Heat use?

- Avoid needless consumption (eg. more efficient equipment and operation)
- Recover higher-grade ‘waste heat’ as much as possible (HEN)
Pinch Analysis: Composite Curves

- Composite Curves represent the process heating and cooling duty profiles
- Energy Targets are an excellent Benchmarking tool

The Pinch Principle

DO NOT

- use Steam below Pinch
- use CW above Pinch
- transfer heat from process streams above Pinch to process streams below Pinch
Grand Composite Curve - GCC

Used for utilities selection

Finding the Global Optimum \( \Delta T_{\text{min}} \)

Goal is to identify Near-Optimum \( \Delta T_m \) range
Grid Diagram identifies Pinch + XP ht tr

| Stream | Ts°F | Tr°F | MPcp | dH°F/ft²|h
<table>
<thead>
<tr>
<th></th>
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<td>H1</td>
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<td>-626</td>
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<tr>
<td>H2</td>
<td>356</td>
<td>176</td>
<td>75.9</td>
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<td>C1</td>
<td>140</td>
<td>212</td>
<td>151</td>
<td>-1052</td>
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<tr>
<td>C2</td>
<td>86</td>
<td>248</td>
<td>68.3</td>
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</table>

Pinch

\[ \Delta T_{min} = 18^\circ \]

XP ht tr is in this HX

Driving Force Plot – HX placement in HEN

Bad Match

Good match
Styrene Plant – new design, Japan (1)

Heat Recovery in Contractor's design

Styrene Plant – new design, Japan (2)

Heat Recovery in optimized Pinch design
Styrene Plant – new design, Japan (3)

<table>
<thead>
<tr>
<th>Description</th>
<th>Contractor's initial design</th>
<th>Optimized pinch design</th>
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<tbody>
<tr>
<td>Heat Recovery, MMBl/h</td>
<td>11.0</td>
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<tr>
<td>Utility Consumption</td>
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<tr>
<td>Steam, MMBl/h</td>
<td>120.4</td>
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<tr>
<td>Cooling water, MMBl/h</td>
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<tr>
<td>Energy cost, K$/yr</td>
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<td>Installed Capital costs, K$</td>
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<td>Heat Exch Network</td>
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<td>Boiler</td>
<td>1235</td>
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<td>Cooling Tower</td>
<td>1510</td>
<td>1029</td>
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<tr>
<td>Total</td>
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Savings of Optimized vs Initial

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<tr>
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<th>Initial</th>
<th>Optimized</th>
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<td>1656</td>
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<tr>
<td>%</td>
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Save both Capital Cost and Energy

Appropriate Placement - Cogeneration

No improvement in system $\eta$

100% conversion of $Q \rightarrow W$
Optimum Utilities: Total Site Analysis

Curves are composites of the RESIDUAL heating and cooling duty segments from the GCCs of individual process units.

Typical On-line CHP s/w Architecture

Real-Time Optimizer finds the best way to operate all utilities subject to contractual, environmental and operational constraints.
Typical Savings = 4-5% vs Std practice

Y axis = Deviation from Optimum = Remaining Savings Opportunity

Workflow integrating Pinch Design method

- First structural optimization, using Pinch Analysis
- Then parametric optimization, using simulation models
Magnitude of Savings = \( f(\text{Payback}) \)

If you set unrealistic ROI requirements, you will FAIL

Why use Pinch Analysis?

- Systematic procedure can find best flowsheet structure, even (in fact especially) for very complex plants
- Quicker + cheaper than traditional approach
- Rigorous energy targets; we know when to quit
- Saves energy and capital without sacrificing safety, operating flexibility, or reliability
- For new plant design, there is an optimum time to do it; but Mgmt needs to be made aware.
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PERFORMANCE MONITORING

Performance Metrics - KPIs and EPIs

<table>
<thead>
<tr>
<th>INDEX TYPE</th>
<th>APPLICATIONS</th>
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<td></td>
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</tbody>
</table>
Necessary Features of Good KPIs

- **Directional Consistency**: When we do something good (e.g. make more profit), the KPI should get better.

- **Magnitude Consistency**: The magnitude of change in the Index should closely match the change in profit, or efficiency, or whatever it is we are measuring.

All KPIs must meet these 2 tests.
Major International O&G Co, 15 plants

90 MBDoe saved in 6 yr; 50% target over 10 yr


Benefits of Systematic PEO Approach

PEO Creates More and Better Solutions.
>>> Twice as much implemented in half the time!

With PEO NPV = 2X
W/O PEO NPV = X

Kumana & Associates, Houston, Texas © 2017
Case Study – generic BioTech plant

- High-value biomass product
- Fermentation + evaporation + drying
- Design based on scale-up of lab process
- 8000 hours per yr operation
Simplified PFD

[Diagram of simplified PFD]

Base Case Utility Consumption & Costs

<table>
<thead>
<tr>
<th>Utility</th>
<th>Exist Load</th>
<th>Cost $/MMBtu</th>
<th>K$/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 atm</td>
<td>0</td>
<td>4.5</td>
<td>0</td>
</tr>
<tr>
<td>175 atm</td>
<td>24.0</td>
<td>4.4</td>
<td>845</td>
</tr>
<tr>
<td>BFW</td>
<td>0</td>
<td>-0.5</td>
<td>0</td>
</tr>
<tr>
<td>Air</td>
<td>0</td>
<td>0.4</td>
<td>0</td>
</tr>
<tr>
<td>CW</td>
<td>16.0</td>
<td>0.9</td>
<td>121</td>
</tr>
<tr>
<td>Refrig</td>
<td>0.4</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Elec. kw</td>
<td>0</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>WW, gpm</td>
<td>138</td>
<td>3.5</td>
<td>233</td>
</tr>
</tbody>
</table>

(includes Dryer steam duty)

What would YOU do to improve process efficiency & economics?
Level 1 PEO idea: Btm Cycle Cogen

- Operate Boiler at max design pr (600 psig)
- Add new superheating section (to 700 F)
- Add new Back Pressure Stm Turb exhausting at 175 psig

PRELIM RESULT
Good economics
Warrants more study

Level 2 PEO study: Energy Targets

<table>
<thead>
<tr>
<th>BASE CASE (EXISTING)</th>
<th>Cp r/lb</th>
<th>Ts, F</th>
<th>Th, F</th>
<th>MMBtu/h</th>
<th>type</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Cp r/lb</td>
<td>Ts, F</td>
<td>Th, F</td>
<td>MMBtu/h</td>
<td>type</td>
</tr>
<tr>
<td>1 Fermenter cooling duty</td>
<td>0.0</td>
<td>60</td>
<td>68</td>
<td>0.42</td>
<td>H</td>
</tr>
<tr>
<td>2 Evap fixed preheat duty</td>
<td>0.85</td>
<td>60</td>
<td>126</td>
<td>1.12</td>
<td>C</td>
</tr>
<tr>
<td>3 Evap vaporization duty</td>
<td>10</td>
<td>126</td>
<td>126</td>
<td>12.3</td>
<td>C</td>
</tr>
<tr>
<td>4 Evap condenser duty</td>
<td>11.5</td>
<td>126</td>
<td>129</td>
<td>11.8</td>
<td>H</td>
</tr>
<tr>
<td>5 Vac jet exhaust vapor</td>
<td>3.63</td>
<td>140</td>
<td>140</td>
<td>3.79</td>
<td>H</td>
</tr>
<tr>
<td>6 WW effluent (combined)</td>
<td>0.2</td>
<td>130</td>
<td>123</td>
<td>1.27</td>
<td>H</td>
</tr>
<tr>
<td>7 Dryer air supply preheat</td>
<td>12.85</td>
<td>240</td>
<td>120</td>
<td>0.53</td>
<td>H</td>
</tr>
<tr>
<td>8 Product drying duty</td>
<td>6.9</td>
<td>120</td>
<td>120</td>
<td>6.38</td>
<td>C</td>
</tr>
<tr>
<td>9 Dryer exhaust gas (to dew pt)</td>
<td>0.75</td>
<td>240</td>
<td>170</td>
<td>0.42</td>
<td>H</td>
</tr>
</tbody>
</table>

Qₙ target = 15.2 MMBtu/h, vs 24 MMBtu/h actual use
Grand Composite Curve → partial MVR

Revised CCs with right-sized MVR
PFD for Optimum Process Configuration

Optimized Utility Costs & Savings

<table>
<thead>
<tr>
<th>Energy supplies</th>
<th>Energy prices</th>
<th>Existing design usage</th>
<th>Optimized design usage</th>
<th>Cost Savings</th>
<th>%</th>
<th>K$/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDIU</td>
<td>5.7 MMBtu</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>175 STM</td>
<td>5.5 MMBtu</td>
<td>24.0</td>
<td>1056</td>
<td>9.5</td>
<td>413</td>
<td>50</td>
</tr>
<tr>
<td>BFV</td>
<td>0.5 MMBtu</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>air</td>
<td>0.4 MMBtu</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CW</td>
<td>0.9 MMBtu</td>
<td>16.6</td>
<td>119</td>
<td>1.7</td>
<td>12</td>
<td>90</td>
</tr>
<tr>
<td>Refrigeration</td>
<td>6 MMBtu</td>
<td>0.4</td>
<td>20</td>
<td>0.4</td>
<td>20</td>
<td>0</td>
</tr>
<tr>
<td>ELEC, kw</td>
<td>0.05 kw</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>WWT, gpm</td>
<td>3.5 gpm</td>
<td>100 gpm</td>
<td>136</td>
<td>233</td>
<td>30</td>
<td>51</td>
</tr>
</tbody>
</table>

- Minor changes → Major opex savings (energy + CO2 + WWT)
- New cream separator + recycle improves yield
- New fermenter cooling design saved 50% of Rfg (not described)
- 60% smaller cogeneration project → capital savings
- Negligible technical risk; Zero commercial risk
- Straight-forward methodology (minimal trial & error)