The Industrial Energy Manager's Essential Tool Kit

Energy Managers' Workshop

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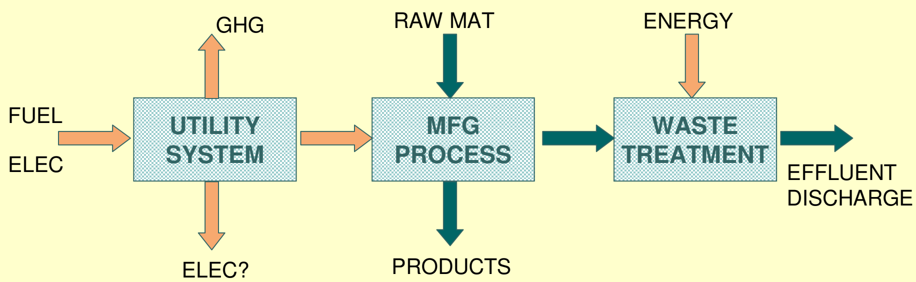
Outline

- Background
- Technical Approach
- Portfolio of Tools and Techniques
- Case Study (Lagniappe)

Industrial Processes – Inputs and Outputs



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

	THROUGHPUT OR CAPACITY	WASTE TREATMENT	ENERGY COST	GHG EMISSIONS
YIELD + KINETICS	↑	↓	↑	↑
UNIT OPERATIONS	↑	↓	↓	↓
OPTIMUM RECYCLE	↑	↓	↓	↓
ENERGY EFF (USAGE)	↔	↔	↓	↓
ENERGY EFF (SUPPLY)	↔	↔	↓	↓

Ideally, we should consider both Process and Energy on Integrated Basis

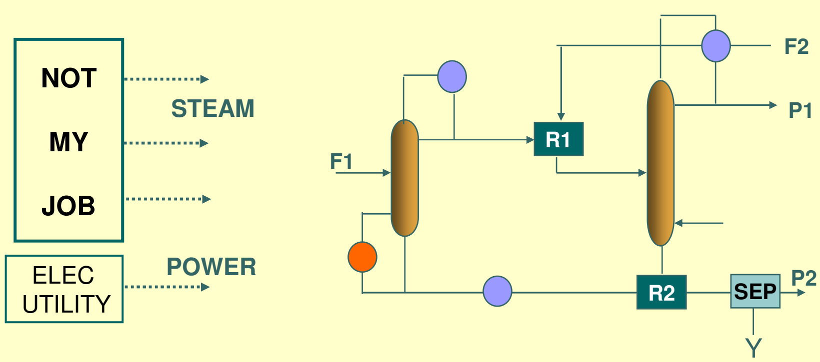
- PROCESS MODIFICATIONS

→ Potentially Huge Impact, but Higher Cap Cost + some Potential Risk

- ENERGY EFFICIENCY OPTIMIZATION

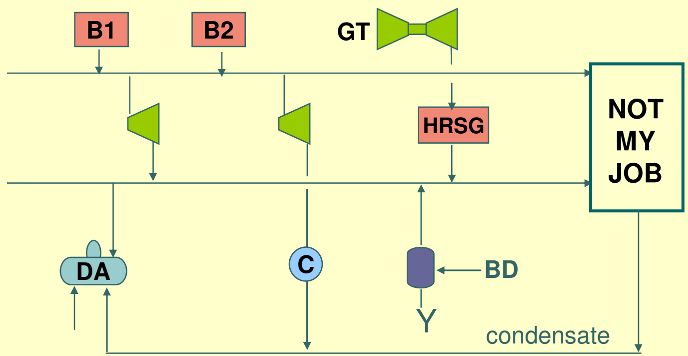
→ Smaller Impact, but Lower Cap Costs & Almost Zero Risk

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

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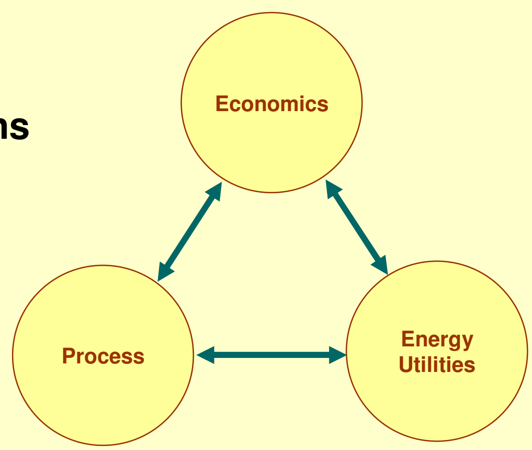
Integrated Optimization Viewpoint

- **Energy**
- **Emissions**
- **Capacity**



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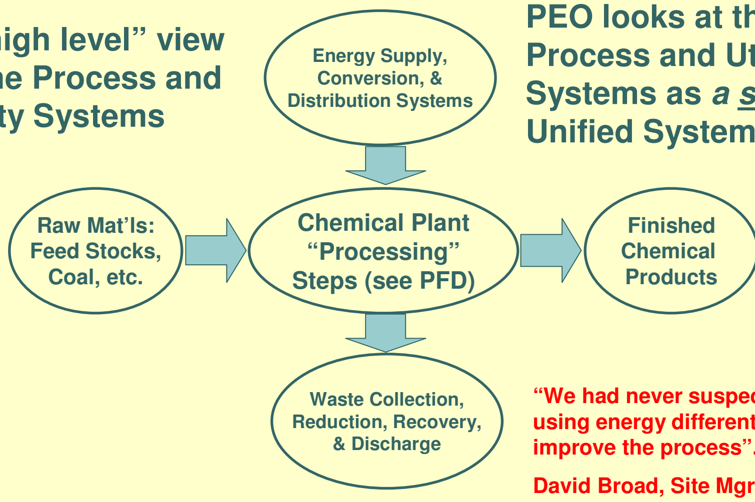
Process Energy Optimization (PEO)

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

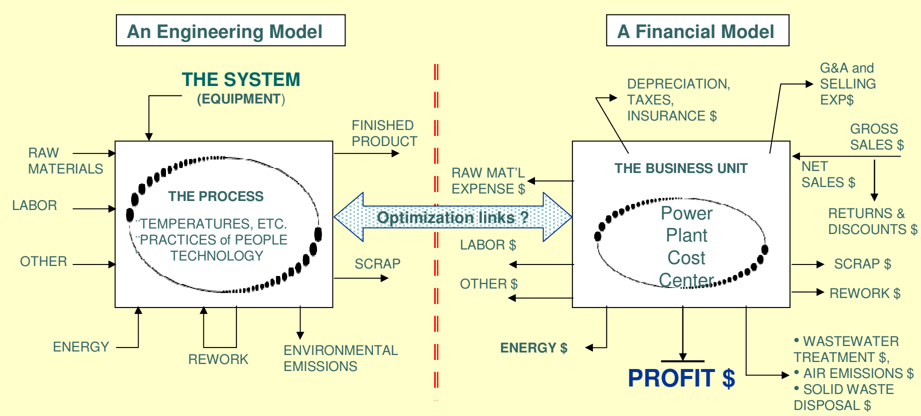
PEO looks at the Process and Utility Systems as *a* ***single*** Unified System



"We had never suspected that using energy differently can improve the process".

David Broad, Site Mgr. BASF

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



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

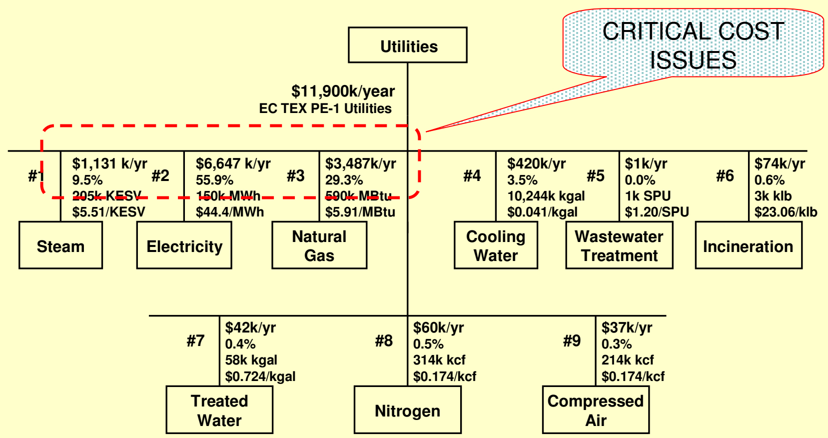
Level 1

- 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

Levels 2 & 3

Example of 1-line Cost Flow Diagram

Utilities: Major Chemical Plant site, Texas



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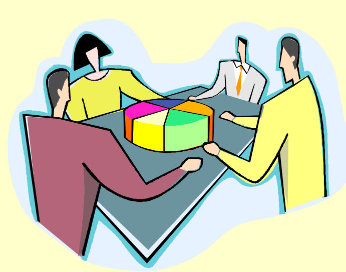
Structured Brainstorming w/ Stakeholders



*Involves Key People on an '**AS NEEDED**' basis: Only One Week per Mfg. Dept.*

Site Participants Include:

- Site & Mfg. Unit Mgmt.
- Raw Matls./Interm. Supplier
- Process Tech. Experts
- Plant Shift Operations Rep.
- Maintenance Specialist
- Finance/Business Rep.

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

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Summary of Level 1 study

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

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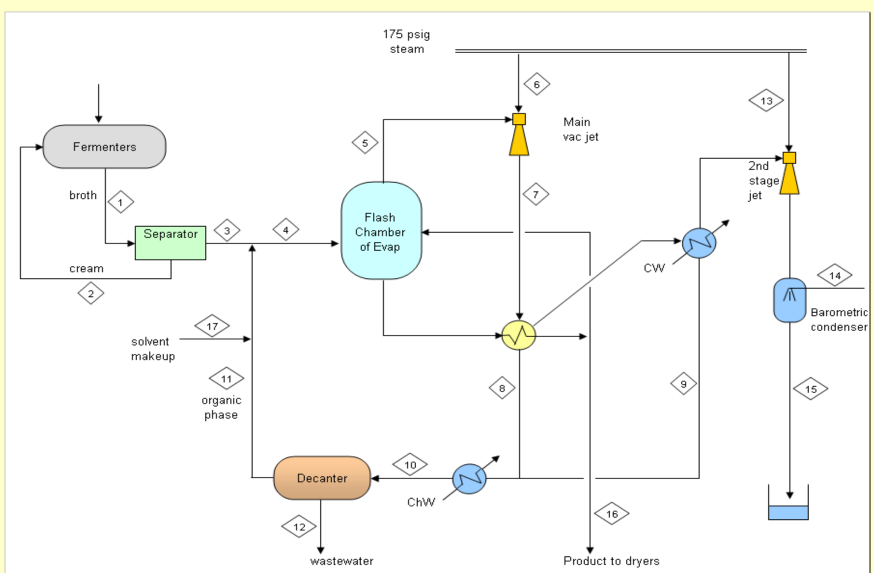
Heat and Material Balance Simulation Models (Process + Utilities)

- 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

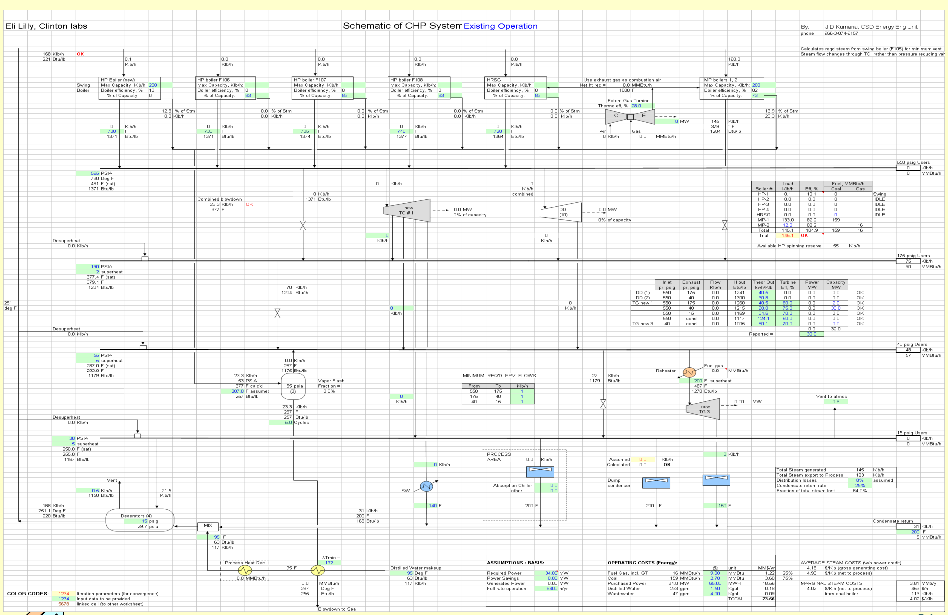


Example HMB model – biotech plant

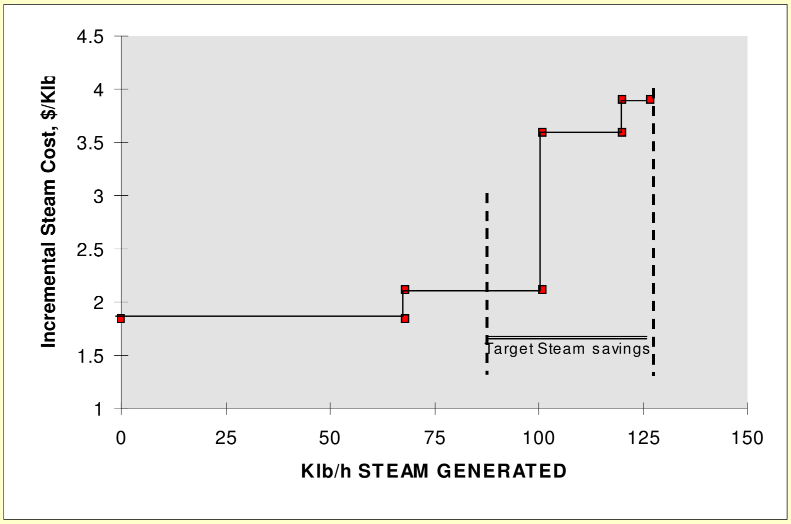
Material and Heat Balance (approximate)				Fermenter broth feed rate			5.0	Klb/h of water			
				Motive/suction ratio in Vac Jet			10.0	to be verified with Mfr			
				Latent heat of vaporization, AA			212	Btu/lb at 120F (217 at 50F)			
y = -1.6327x2 - 19.904x + 1036				Latent heat of vaporization, H2O			1025	Btu/lb at 120F; pp =		1.7	psia partial
										100	mm Hg tot
		Stream number ...									
Material	MW	1	2	3	4	5	6	7	8	9	
SS	1000	0.10	0.10	0	0	0	0	0	0	0	
DS	200	0.05	0.00	0.05	0.05	0	0	0	0	0	
water	18	5.00	1.62	3.38	3.54				3.70	32.92	
steam	18					2.92	33.7	36.6			
Cs-OH	88	0	0	0	2.21	2.19	0	2.19	0.22	1.97	
	Total Klb/h	5.15	1.72	3.44	5.80	5.12	33.7	38.8	3.92	34.89	
	Moles/h	278	90	188	222	187	1872	2059	208	1851	
	Pr, mm Hg abs	760	760	760	760	100	9808	760	760	760	
	Temp, F	60	60	60		120	377	212	210	150	
	% SS	2	6	0	0	0	0	0	0	0	
	% DS	1	0	1.5	0	0	0	0	0	0	
	wt% AA	0	0	0	38.4	42.9	0	5.7	5.7	5.7	
	Ht tr duty					3.46		36.0	3.63	34.4	

		Stream number ...									
Material	MW	10	11	12	13	14	15	16	17	18	
SS	1000	0	0	0	0	0	0	0	0		
DS	200	0	0	0	0	0	0	0.05	0		
water	18	36.6	0.16	36.5		31.9	33.6	0.46	0		
steam	18				1.7						
Cs-OH	88	2.2	1.56	0.6	0	0	0	0.01	0.64		
	Total Klb/h	38.8	1.72	37.1	1.7	31.9	33.6	0.53	0.64	0	
	Moles/h	2059	27	2033	94	1773	1867	26	7	0	
	Pr, mm Hg abs	760	760	760	9808	760	760	760	760		
	Temp, F	68	68	68	377	85	140	125	80		
	% SS	0	0	0	0	0	0	0	0		
	% DS	0	0	0	0	0	0	10	0		
	wt% AA	5.7	90.8	1.7	0	0	0	2.63	100		
	Ht tr duty	3.1			1.6						

CHP System Simulation Model



Marginal steam prices - discontinuous



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- STRUCTURED BRAIN-STORMING

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Levels 2 & 3

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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

Motherhood and Apple Pie

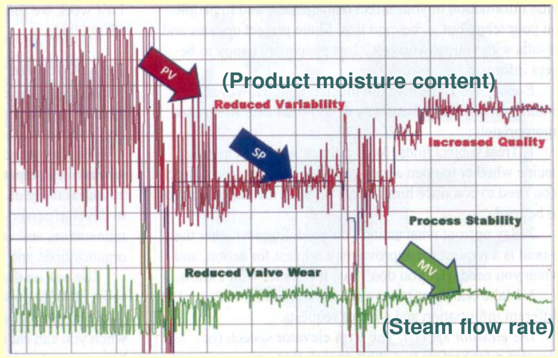
- Minimize running spares
- Avoid keeping equipment on hot standby
- Maintain Steam traps, insulation
- Steam/Air leak detection & repair program
- Cooling water treatment

More Advanced methods

- Boiler & Furnace O_2 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 (eg. prod. moisture %)
SP = set point
MV = Manipulated Variable (eg. steam flow)

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REF. G. Buckbee, "Closing the Gap between Engineers and Management", *Chem Eng Prog*, May 2010

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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)

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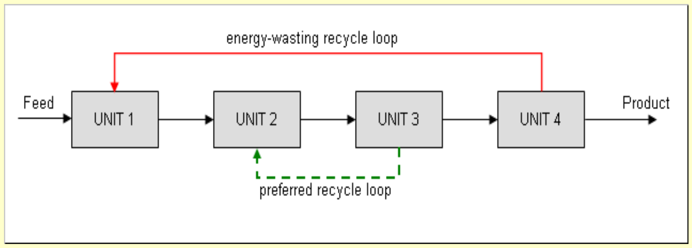
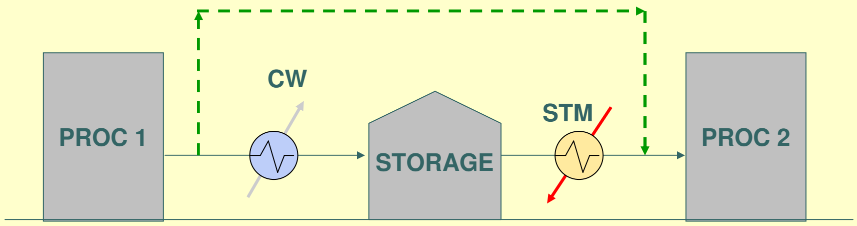
Examples of Simple Piping mods





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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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Levels 2 & 3

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 %

Variable Speed Control compared with Throttle Control

		Company:	CONFIDENTIAL
		Department:	
Applic:	AM crude pump	Handled by:	J D Kumana
Pump:	G-302	Date:	10-Jun-05

INITIAL DATA:

Liquid density (water = 62.2 @ 80 °F)	D (lb/cu ft)	53.7	OK	
Pump nominal flow	Qn (GPM)	1000		= 134 CFM
Rated head (pipe & valve friction + static)	Hn (ft)	1600		
Pump maximum head (at zero flow)	Hmax (ft)	1725	OK	
Static head of the system	Hst (ft)	50	OK	
Nominal efficiency of the pump	np (%)	75	OK	
Valve friction head (zero if not removed)	Hv (ft)	0	OK	
Rated power of motor	P1 (hp)	600	OK	Pi = 464 hp
Nominal efficiency of the motor	nm (%)	94	OK	(calc. power)
Nominal efficiency of drive	nVSD (%)	98	OK	
Total operating time per year	Tk (h)	8400	OK	
Price of energy (per kWh)	USD	0.027		

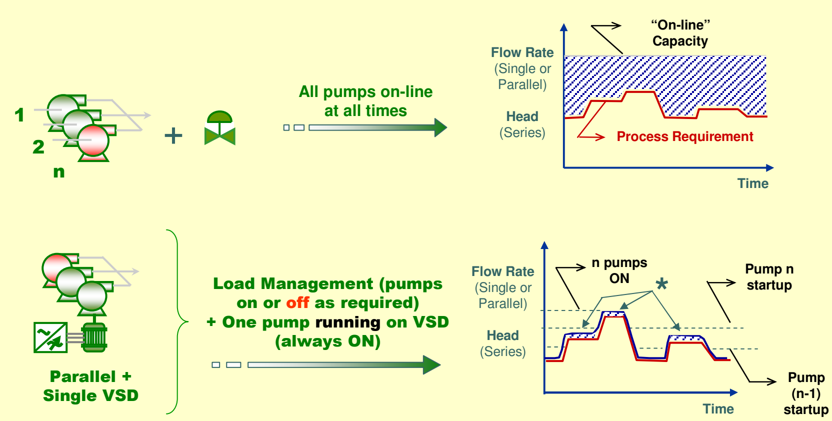
	Flow	CFM	Time (%)	Hours
	30%	300	0	%= 0
Operating time	40%	400	0	%= 0
in different flow rates	50%	500	0	%= 0
as a percentage of the	60%	600	6.3	%= 526.462395543175
total operating time	70%	700	20.2	%= 1696.37883008357
	80%	800	53.8	%= 4515.8774373259
	90%	900	19.8	%= 1661.28133704735
	100%	1000	0	%= 0
The sum must be = 100 %	Sum		100	OK

RESULTS OF CALCULATIONS:

Calculated energy / throttling	2,586,647	kWh
Calculated energy / variable speed	1,683,496	kWh
Total energy savings / year	903,151	kWh
Total energy cost savings / year	24,385	USD
Additional investment costs for drive	135,637	USD
Direct payback time	5.6	Years

SELECT TYPE | PRINT | GRAPHICS

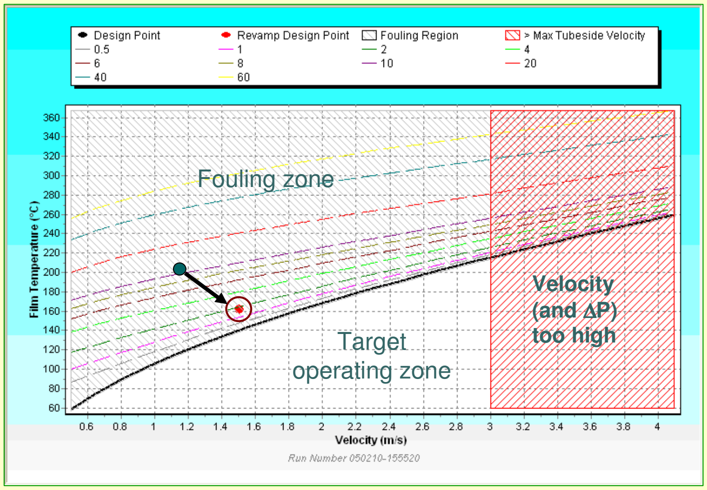
Pump Networks with and without VFDs



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

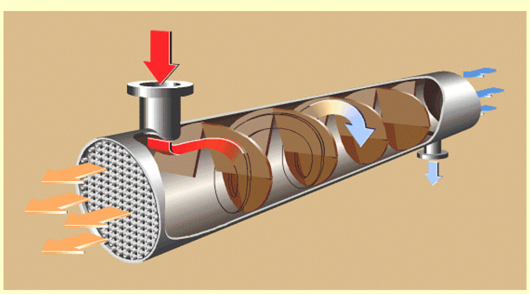
Intermediate scenario of Load Mgmt, where un-needed pumps are turned off, is not shown

HX modification strategy



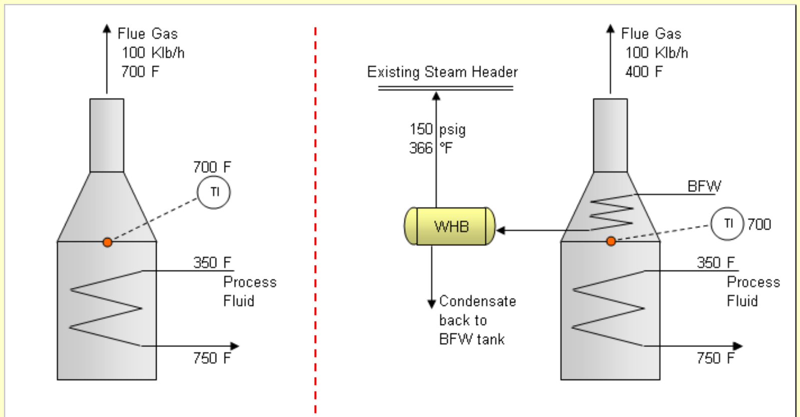
Goal = Move operating point towards Target Zone

Shell-side Helical Baffles



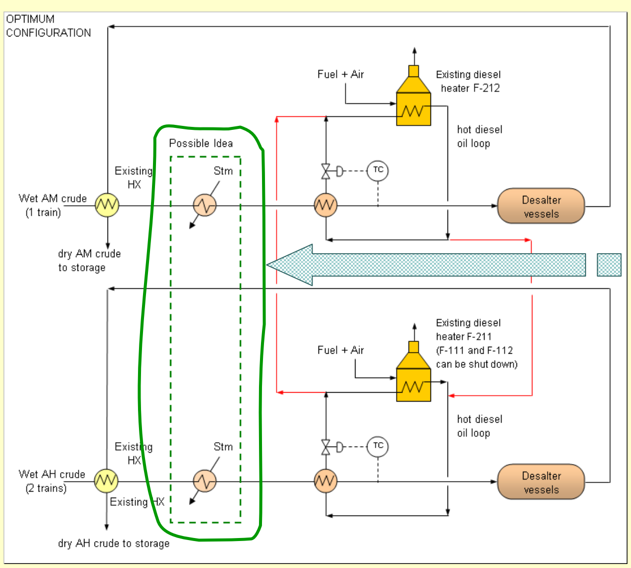
BETTER TEMP PROFILE AND FLOW PATTERN

Furnace/Boiler Air Preheating



	Case 1	Case 2
Process duty, MMBtu/h	84.0	84.0
WHB duty, MMBtu/h	0	9.0
Fuel gas flow, Klb/h	5.0	5.0
Fuel Input (HHV), MMBtu/h	107.5	107.5
Overall Efficiency (HHV), %	78.1	86.5

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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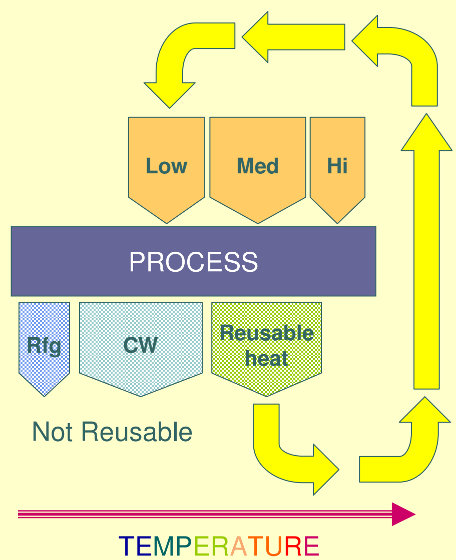
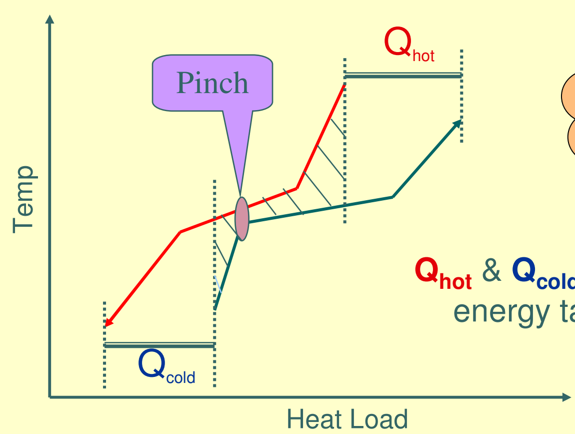
How can we reduce Process Heat use?

- Avoid needless consumption (eg. more efficient equipment and operation)
- Recover higher-grade 'waste heat' as much as possible (HEN)



Pinch Analysis: Composite Curves

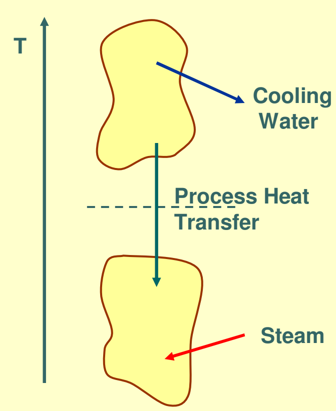


Used for Energy Targeting

Q_{hot} & Q_{cold} are the energy targets

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

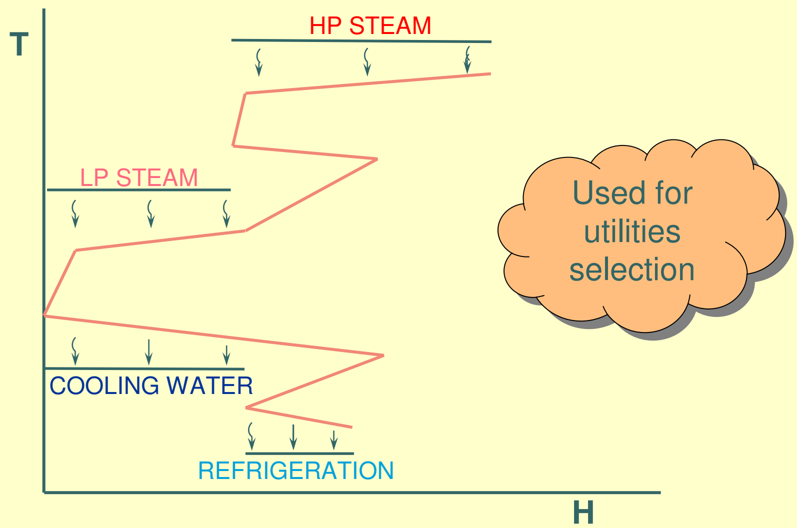
The Pinch Principle



<u>DO NOT</u>

- **use Steam below Pinch**
- **use CW above Pinch**
- **transfer heat from process streams above Pinch to process streams below Pinch**

Grand Composite Curve - GCC



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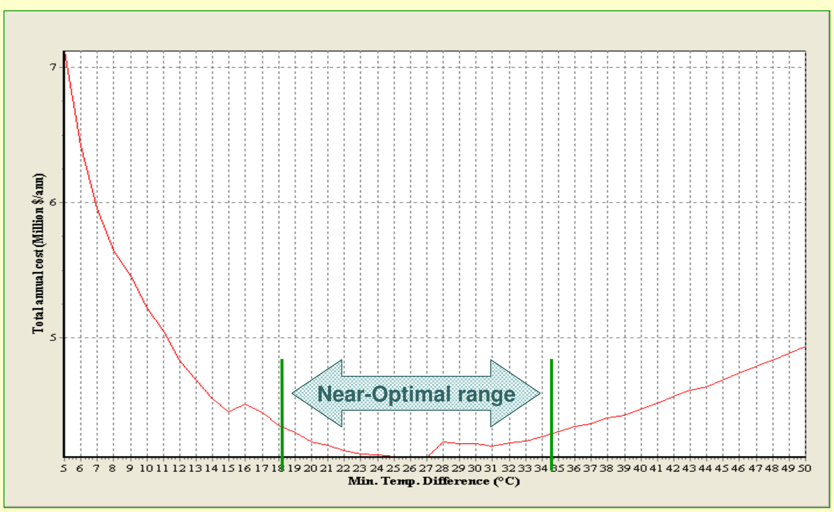
Finding the Global Optimum ΔTmin



Goal is to identify Near-Optimum ΔTm range

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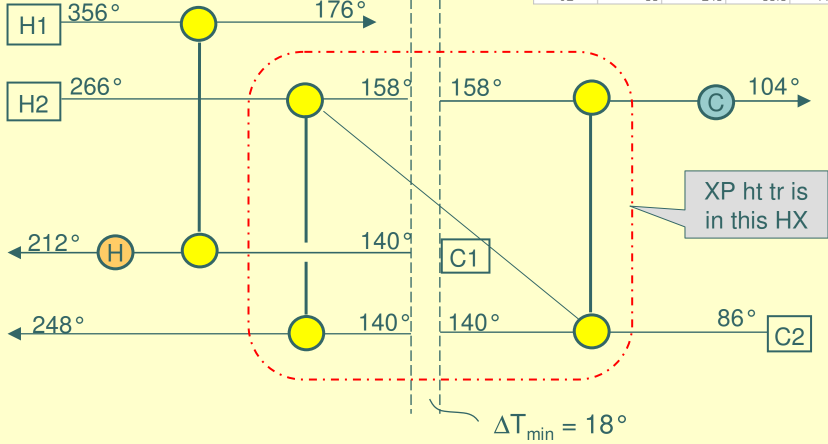
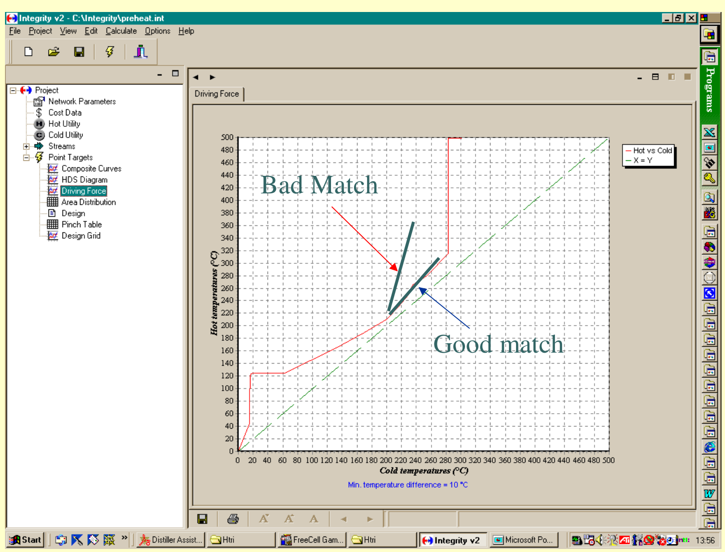
Grid Diagram identifies Pinch + XP ht tr

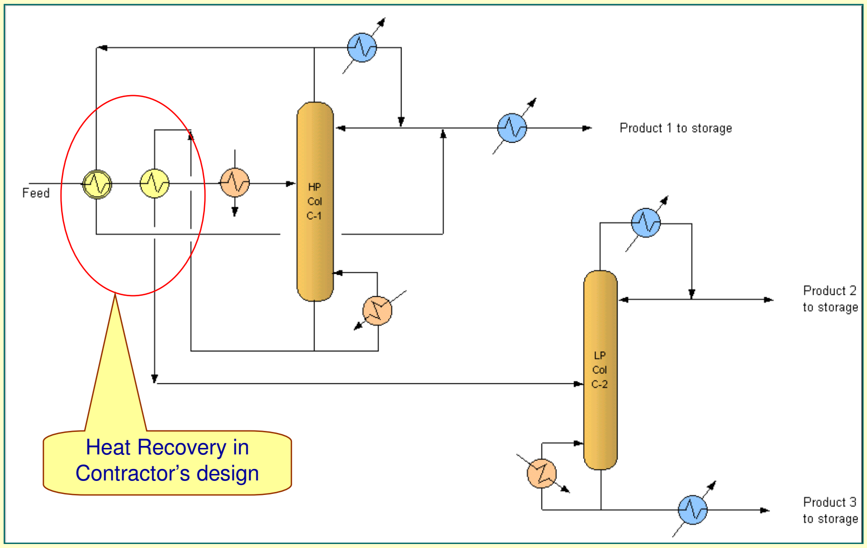
Stream	Ts °F	Tt F	MCp KBtu/h-F	ΔH KBtu/h
H1	356	176	37.9	-6826
H2	266	104	75.8	-12287
C1	140	212	151.7	10922
C2	86	248	68.3	11058



Driving Force Plot – HX placement in HEN



Styrene Plant – new design, Japan (1)



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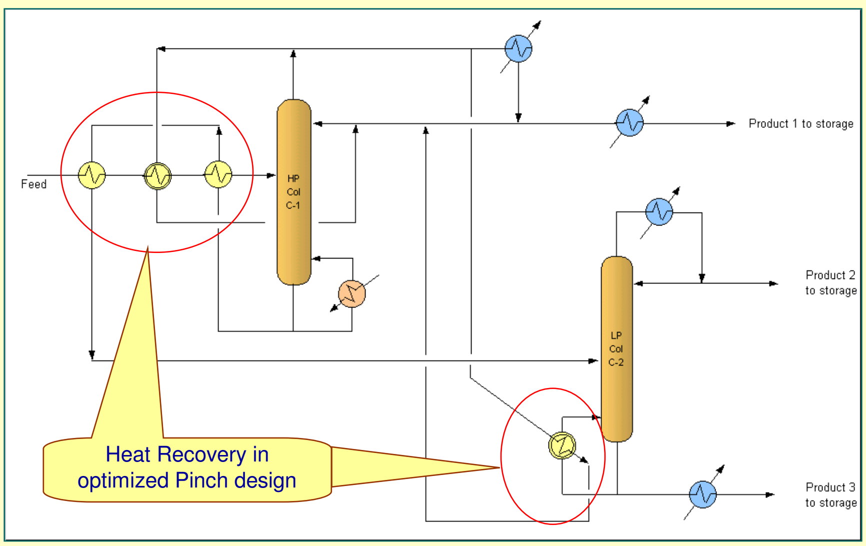
Styrene Plant – new design, Japan (2)



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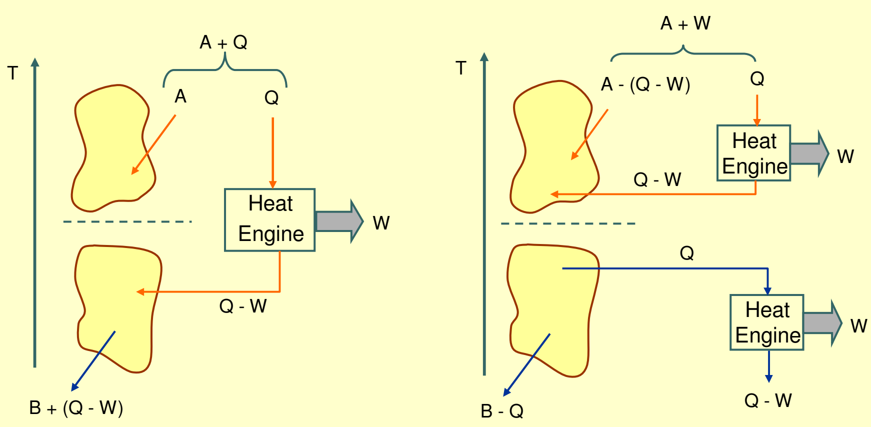
Styrene Plant – new design, Japan (3)

Description	Contractor's initial design	Optimized **pinch** design
Heat Recovery, MMBtu/h	11.0	67.8
Utility Consumption		
Steam, MMBtu/h	120.4	63.5
Cooling water, MMBtu/h	120.6	63.8
Energy cost, K$/yr	3595	1923
Installed Capital costs, K$		
Heat Exch Network	820	741
Boiler	1235	747
Cooling Tower	1518	1029
Total	3573	2518
Savings of Optimized vs Initial		
Utility cost, K$/yr	0	1672
, %	0	46.5
Capital cost, K$	0	1055
, %	0	29.5

Save both Capital Cost and Energy

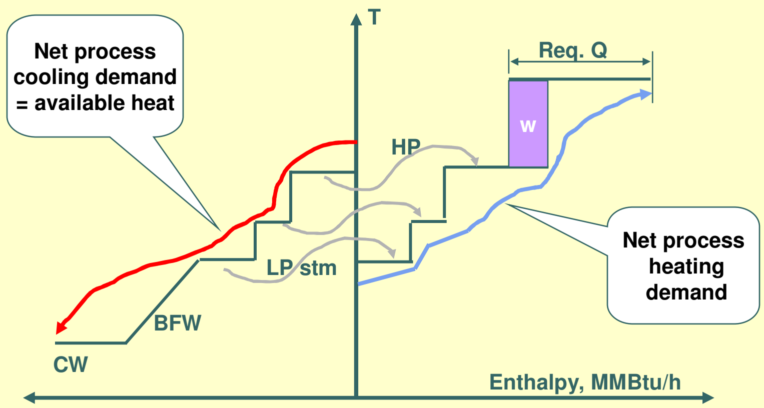
Appropriate Placement - Cogeneration



No improvement in system η

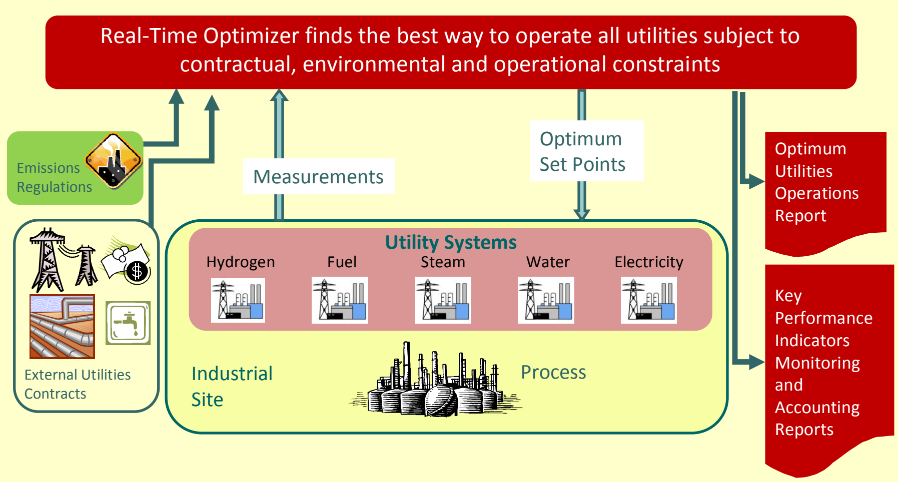
100% conversion of Q → W

Optimum Utilities: Total Site Analysis

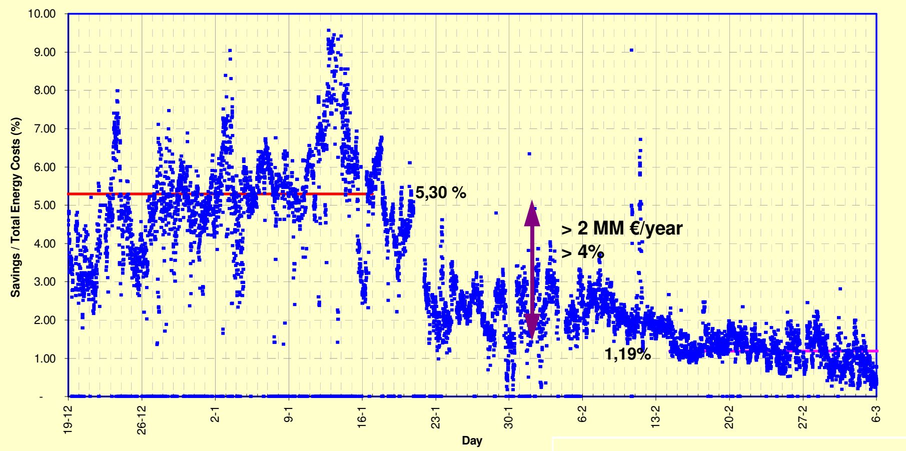


Curves are composites of the RESIDUAL heating and cooling duty segments from the GCCs of individual process units

Typical On-line CHP s/w Architecture

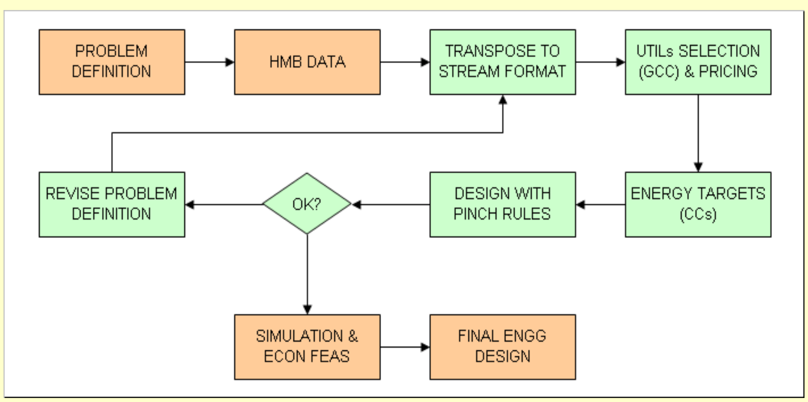


Typical Savings = 4-5% vs Std practice



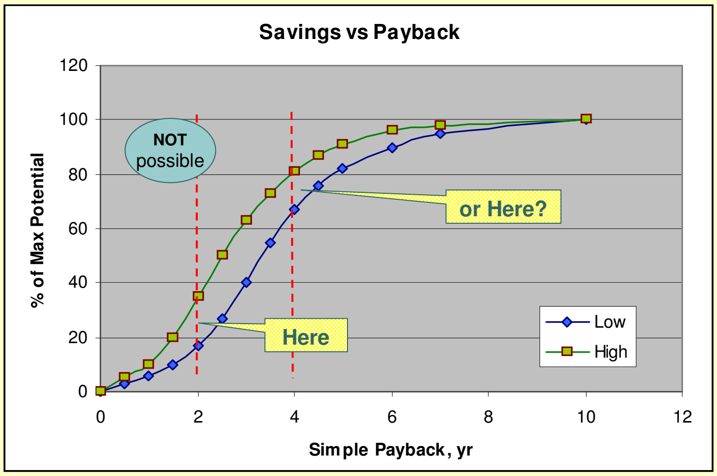
Y axis = Deviation from Optimum = Remaining Savings Opportunity

Workflow integrating Pinch Design method



- First structural optimization, using Pinch Analysis
- Then parametric optimization, using simulation models

Magnitude of Savings = *f* (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.

Technical Tool Kit

- “COST FLOW” DIAGRAMS for CCIs
- STRUCTURED BRAIN-STORMING

Level 1

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

Levels 2 & 3

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Performance Metrics - KPIs and EPIs

INDEX TYPE	APPLICATIONS
Corp KPI	• Org efficiency trend • External Benchmarking
Plant EPIs • Product	• Cost Accounting • Economic dispatch • Planning
• Process	• Performance trend monitoring • Operations troubleshooting • Design Improvement
• Equipment	• Process control • Equipment troubleshooting • Targeted maintenance

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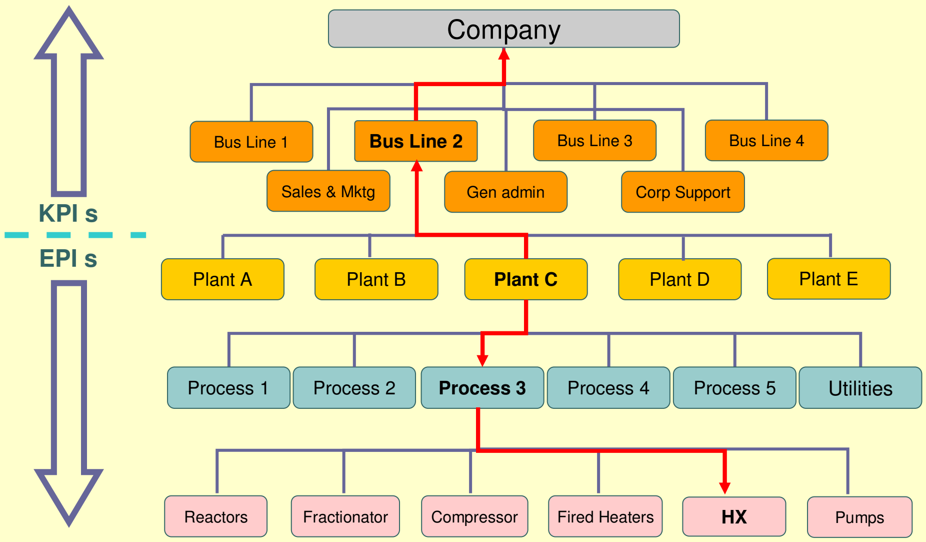
Multi-tier structure – drilldown capability



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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

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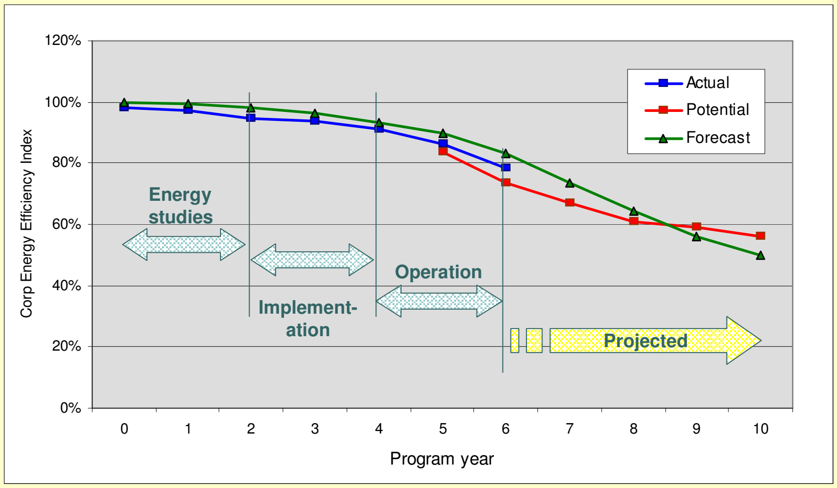
Major International O&G Co, 15 plants



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

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REF. J D Kumana, “Corporate Energy Management Programs: A Case Study”, *Chemical News* (Nov 2010)

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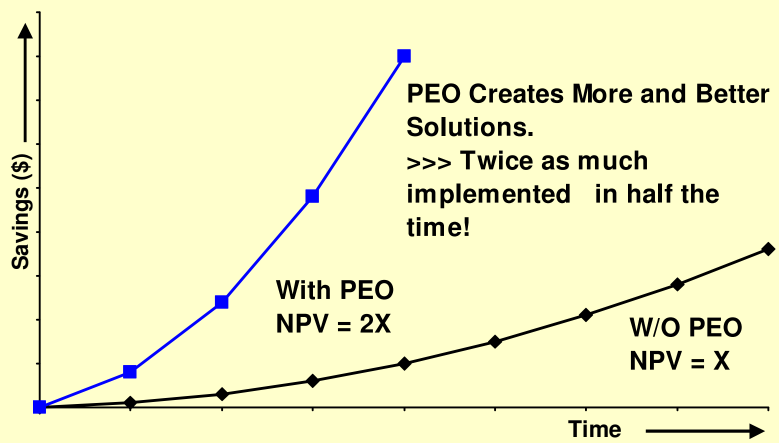
Benefits of Systematic PEO Approach



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The End

Questions ??

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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

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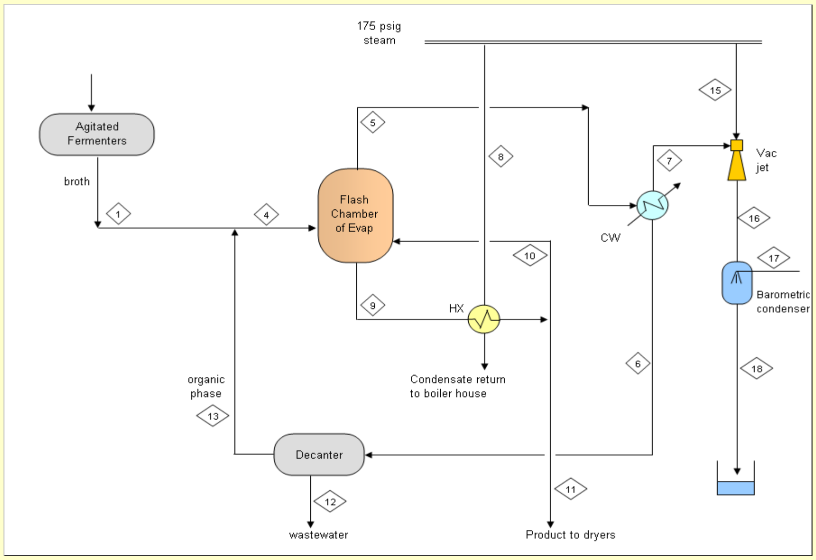
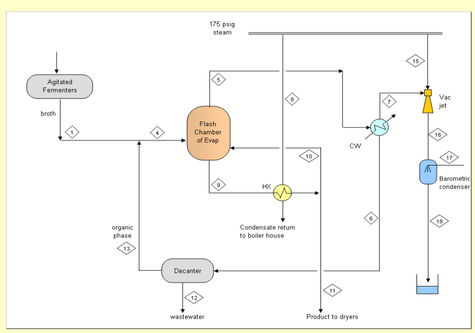
Simplified PFD



Base Case Utility Consumption & Costs

	Exist load	Cost	
	MMBtu/h	$/MMBtu	K$/yr
600 stm	0	4.5	0
175 stm	24.0	4.4	845
BFW	0	-0.5	0
air	0	0.4	0
CW	16.8	0.9	121
Refrig	0.4	6	20
Elec, kw	0	0.05	0
WW, gpm	138	3.5	233
			1219

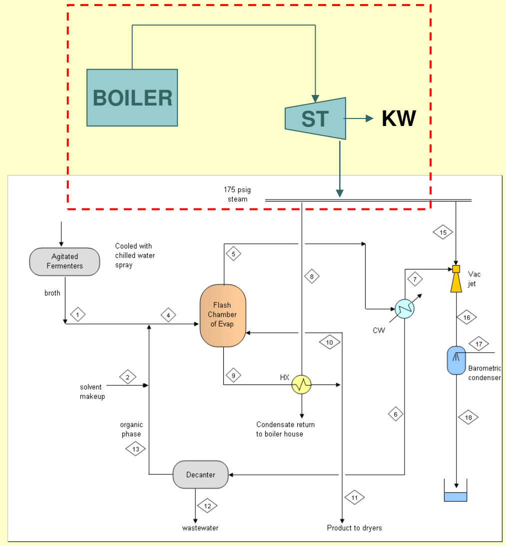
(includes Dryer steam duty)



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**

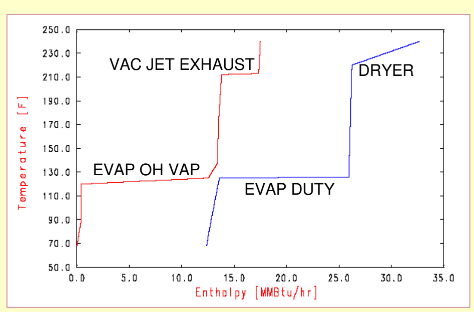


PRELIM RESULT
Good economics
Warrants more study

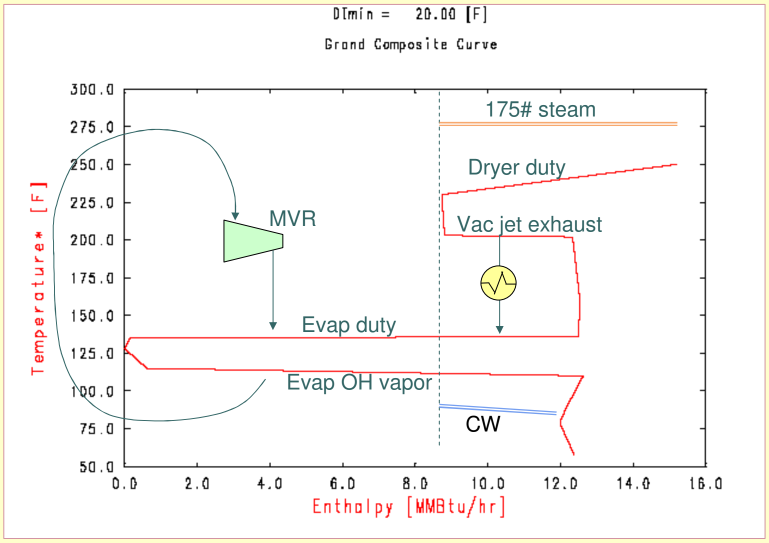
Level 2 PEO study: Energy Targets

BASE CASE (EXISTING)			Cp or λ				
No	Stream Name/ID	M, Klb/h	Btu/lb-F	Ts, F	Tt, F	MMBtu/h	type
1	Fermenter cooling duty	20.0	0.96	90	68	0.42	H
2	Evap feed preheat duty	20.10	0.96	68	126	1.12	C
3	Evap vaporization duty	12.10	1019	125	126	12.3	C
4	Evap condenser duty	11.5	1024	125	120	11.8	H
5	Vac jet exhaust vapor	3.63	1043	213	140	3.79	H
6	WW effluent (combined)	69.2	1.0	138	120	1.27	H
7	Dryer air supply preheat	13.85	0.24	80	240	0.53	C
8	Product drying duty	5.9	1077	220	240	6.39	C
9	Dryer exhaust gas (to dew pt)	19.79	0.30	240	170	0.42	H

Q_H target = 15.2 MMBtu/h, vs 24 MMBtu/h actual use



Grand Composite Curve → partial MVR



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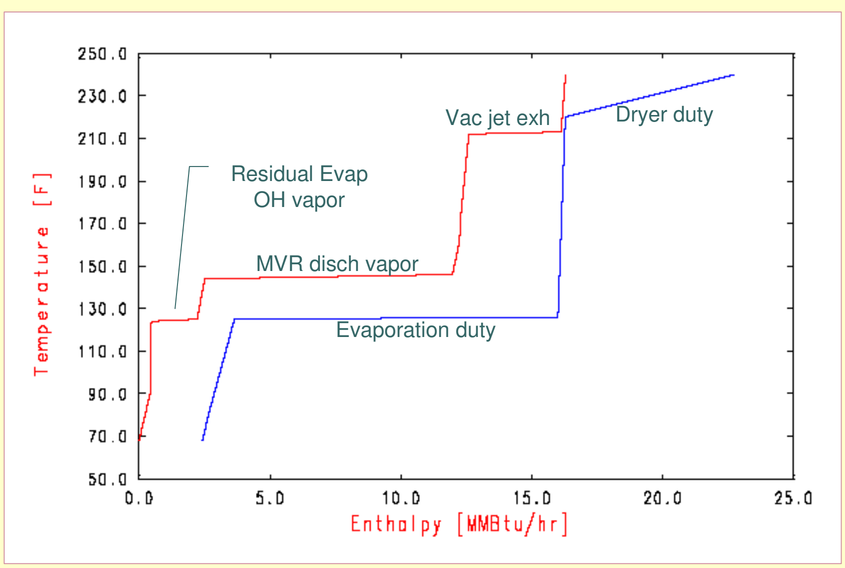
Revised CCs with right-sized MVR



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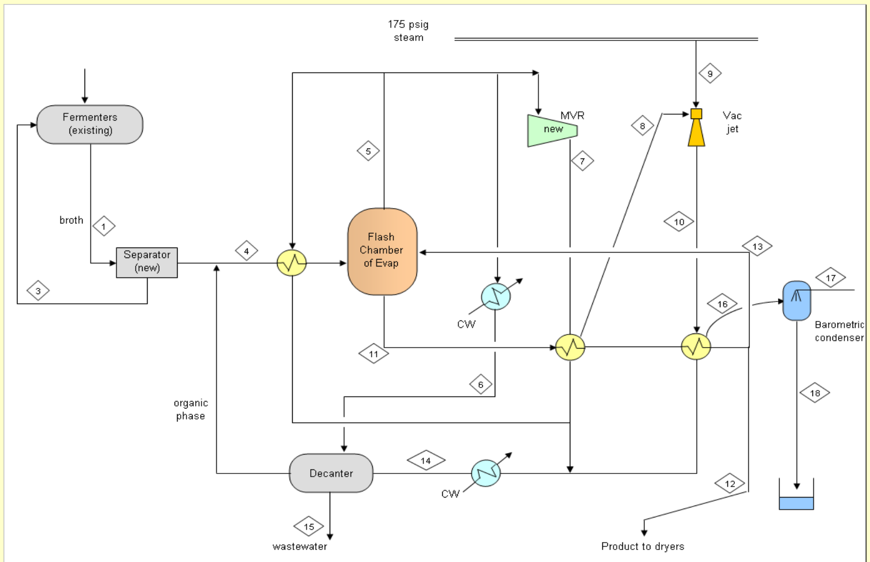
PFD for Optimum Process Configuration



Optimized Utility Costs & Savings

	Energy prices		Existing design		Optimized design		Cost Savings	
	$/unit	units	usage	K$/yr	usage	K$/yr	%	K$/yr
600 stm	6.7	MMBtu	0	0	0	0	0	0
175 stm	5.5	MMBtu	24.0	1056	9.5	418	60	638
BFW	-0.5	MMBtu	0	0	0.9	-4	n/a	4
air	0.4	MMBtu	0	0	0	0	0	0
CW	0.9	MMBtu	16.6	119	1.7	12	90	107
Refrig	6	MMBtu	0.4	20	0.4	20	0	0
Elec, kw	0.05	kwh	0	0	146	58	n/a	-58
WW, gpm	3.5	100 gal	138	233	30	51	78	182
				1428		556	61	872

- Minor changes → Major opex savings (energy + CO_2 + 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)