



Meaningful Energy Efficiency Performance Metrics for the Process Industries

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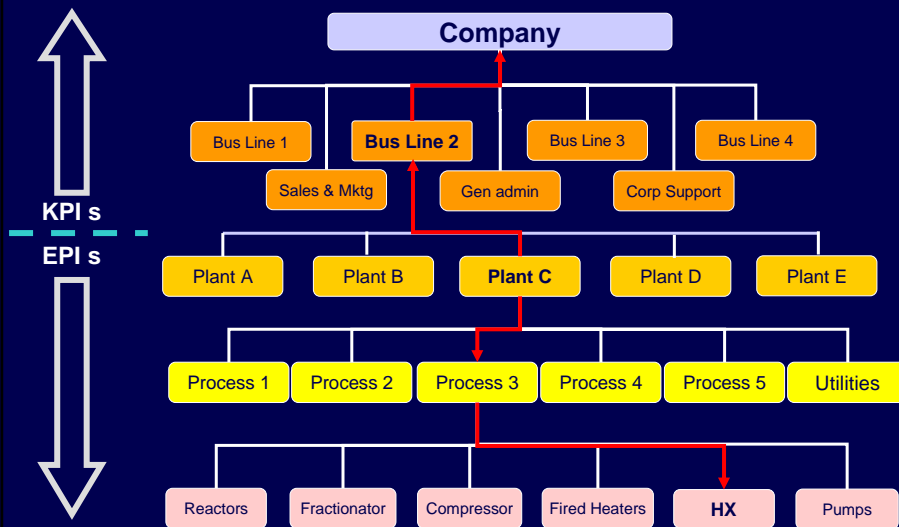
OUTLINE

-
- **Background**
 - Equipment Indices
 - Process Indices
 - Product Indices
 - Overall Corporate KPI
-

TWO TYPES - KPIs AND EPIs

<u>INDEX TYPE</u>	<u>APPLICATIONS</u>
Corp KPI	<ul style="list-style-type: none"> • Org efficiency trend • External Benchmarking
Plant EPIs	<ul style="list-style-type: none"> • Product • Cost Accounting • Economic dispatch • Planning
• Process	<ul style="list-style-type: none"> • Performance trend monitoring • Operations troubleshooting • Design Improvement
• Equipment	<ul style="list-style-type: none"> • Process control • Equipment troubleshooting • Targeted maintenance

MULTI-TIER STRUCTURE – drilldown capability



OBJECTIVES OF PLANT EPIs

- Operations optimization, incl. troubleshooting
- Process Design Improvement
- Benchmarking
 - Historical (vs Base Year) **YES**
 - Competitive (ie. vs peers) **NO**
 - Comparative (ie. vs “standard”) **NO**
- Economic dispatch among multiple plants

KEY REQUIREMENT = isolate the effect of feed rate, composition, and ambient temperature from design and operating efficiency.



DIFFERENT EPIs FOR DIFFERENT APPLICATIONS

	Product	Process	Equipt
Management	x		
Engineers	x	x	x
Operators			x

More than 1 Index per category, eg. for a gas plant

9	Overall (3 per product)
12	Process Unit (2 or 3 per area)
<u>16</u>	Equipment (one each)
37	Total



TWO WAYS TO EXPRESS AN EPI

-
- Absolute, eg. kwh/scf or MMBtu/ton
 - Relative, ie. $\left\{ \frac{\text{actual energy input}}{\text{optimum energy input}} \right\}$

Both are acceptable



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DESIRABLE FEATURES of PLANT EPIs

- Output-based instead of Input-based
- Use simulation model to count and accrue energy inputs for each product
- Use rational allocation procedure to allocate energy when a process has multiple feeds or multiple products

- Highlight anomalous behavior, allowing us to diagnose problems if we know how to interpret the index correctly. It is therefore tool for **PROCESS EFFICIENCY IMPROVEMENT**, which after all, is the ultimate goal
- Provide a consistent method for comparing different plants - can serve as a **BENCHMARKING** tool



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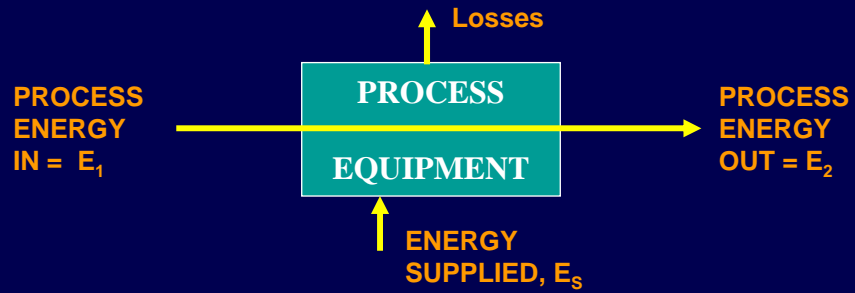


TWO KINDS OF EQUIPMENT

- Energy Consumers:
 - Pumps
 - Compressors
 - Furnaces
 - Distillation columns
- Energy Converters:
 - Boilers
 - Turbines
 - Motors
 - Generators

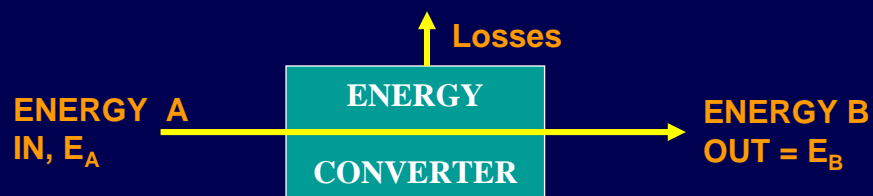


Efficiency for Energy Consumers



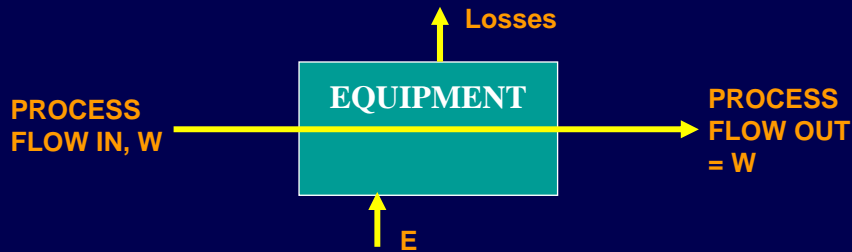
$$\text{Efficiency} = \frac{\text{Useful Energy Absorbed}}{\text{Utility Energy Supplied}} = \frac{E_2 - E_1}{E_s}$$

Efficiency for Energy Converters



$$\text{Efficiency} = \frac{\text{Energy Output}}{\text{Energy Input}} = \frac{E_B}{E_A}$$

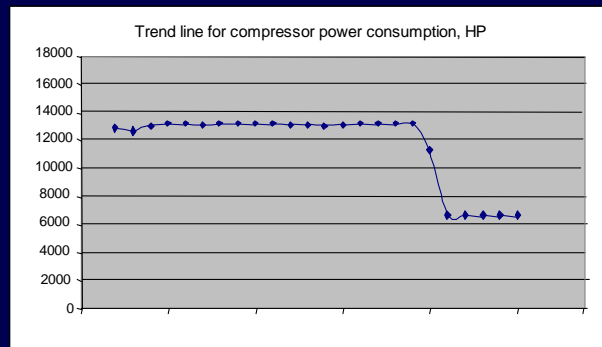
Alternative Formulations for EPI



Two possible ways to express index:

- as intensity: E / W
- as efficiency: $E_{\text{actual}} / E_{\text{theor}}$

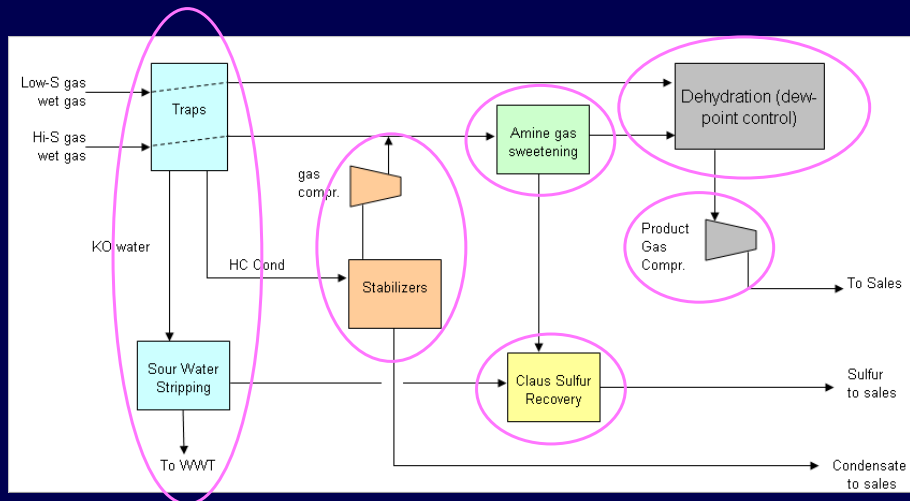
EXAMPLE – COMPRESSOR STATION, GAS PIPELINE



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EXAMPLE of PROCESS EPIs – GAS PLANT



6 main process areas

INDICES, per unit of throughput

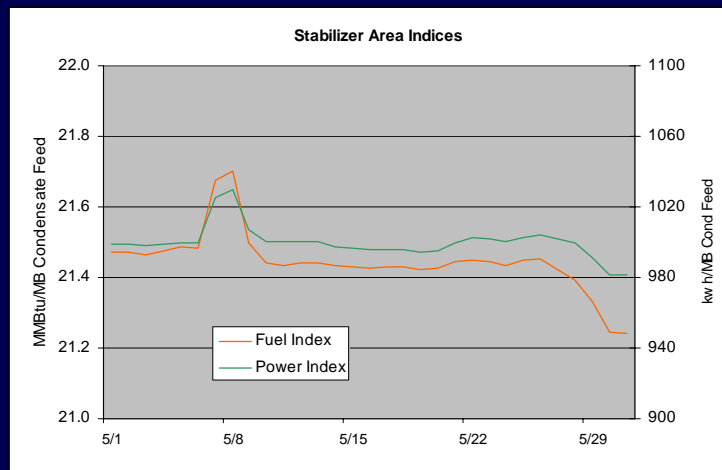
Right choice?
What about acid gas ?

	Inlets	Stabilizer	Gas Treat
Capacity parameter	combined feed gas	Combined cond feed	sweet gas
units	MMscf	1000 barrels (MB)	MMscf
Flow rate, units/day	1269	137	819
Boiler fuel, MMBtu/unit	0.6	18.5	14.1
Proc fuel, MMBtu/unit	0.0	0.0	0.0
Elec power, kwh/unit	1.8	32.7	4.0

	DDPC	Sales Gas Compr	SRU
Capacity parameter	dry sweet gas	HP Sales Gas	sulfur
units	MMscf	MMscf	tonnes
Flow rate, units/day	1116	1101	494
Boiler fuel, MMBtu/unit	0.5	0.0	8.4
Proc fuel, MMBtu/unit	0.0	0.0	2.9
Elec power, kwh/unit	3.4	29.4	1.9

Possible to calculate from Process Simulation Model + live PI data

WHAT DO THESE EPIs TELL US ?



< 1% VARIATION – PROBABLY DUE TO WAY THE SYSTEM IS CONTROLLED
(FIXED ENERGY INPUT NOT TIED TO PROCESS DEMAND)

ANOTHER EXAMPLE, SAME PLANT

Gas Plant

Home Areas EPI

Units Indices - Gas Treat 1

Index Description	Unit	Value	Target	MTD	YTD
DGA Losses (Lb DGA/ MMSCF of Sour Gas)	Lp/MMSCF	0.95	<-1.1	0.95	0.95
LP Steam/DGA	Lb/Cal	2.02	<-1.6	1.53	1.53
Energy(Kw) /MMSCFD Sour gas	Kw/MMSCFD	1.83	<-1.9	1.87	2.02

Click to trend the Index

Gas Treat 2

Index Description	Unit	Value	Target	MTD	YTD
DGA Losses (Lb DGA/ MMSCF of Sour Gas)	Lb/MMSCF	0.95	<-1.1	0.95	0.95
LP Steam/DGA	Lb/Cal	2.02	<-1.6	2.02	2.02
Energy(Kw) /MMSCFD Sour gas	Kw/MMSCFD	1.73	<-1.9	1.78	1117.97

Click to trend the Index

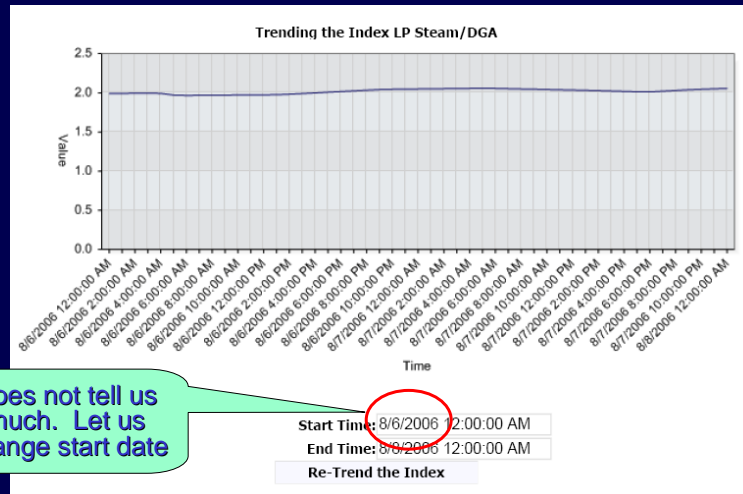
Gas Treat 3

Index Description	Unit	Value	Target	MTD	YTD
DGA Losses (Lb DGA/ MMSCF of Sour Gas)	Lb/MMSCF	0.95	<-1.1	0.95	0.95
LP Steam/DGA	Lb/Cal	1.58	<-1.6	1.58	1.58
Energy(Kw) /MMSCFD Sour gas	Kw/MMSCFD	1.73	<-1.9	1.73	53.76

Click to trend the Index

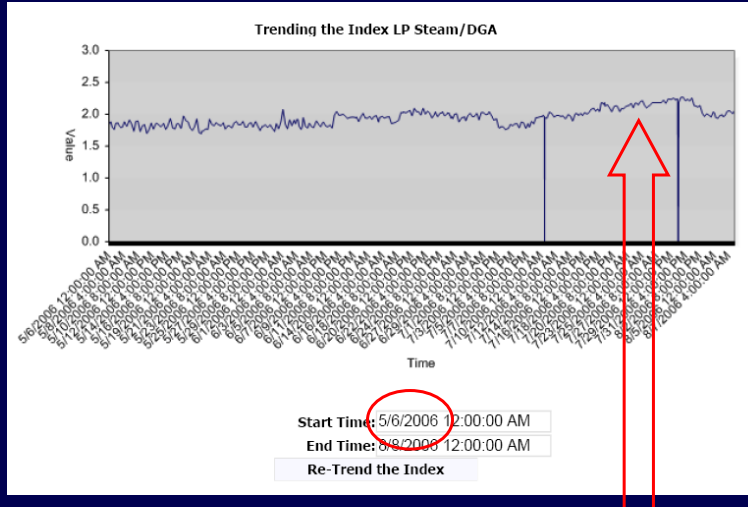
Drill down on problem area (unit 2)

2-DAY TREND CHART



Does not tell us much. Let us change start date

3-MONTH TREND CHART



Steady rise over 2 months, steady rise over last 1 month



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POSSIBLE INTERPRETATIONS of EPI

**KEEP IN MIND THAT PROBLEM IS UNIQUE TO UNIT 2
(others not affected)**

- Faulty flow meter ?
- Defective/damaged control valve ?
- Colder feed to stripper (eg. due to HX fouling) ?
- Other ??

EPIs help Process Engineer to identify anomalies and take corrective action



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MANY POTENTIAL EPIs PER PRODUCT

- Steam
- Fuel (direct-fired)
- Total fuel
- Electrical Power
- Mechanical power
- Total power
- Total energy cost



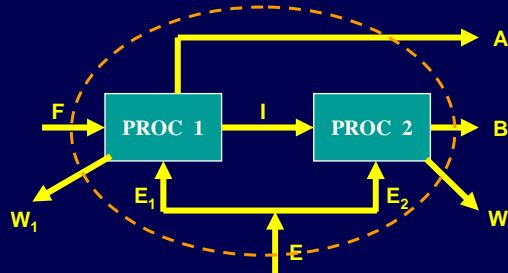
COMPOSITE FORMULATION: Waste disposal cost = 0

$$F = A + B + W$$

$$E = E_1 + E_2 \\ = E_A + E_B$$

$$X_A = A / (F - W)$$

$$X_B = B / (F - W)$$



$$V_A = AC_A - C_F FX_A ; Y_A = V_A / (V_A + V_B) ; E_A = Y_A E$$

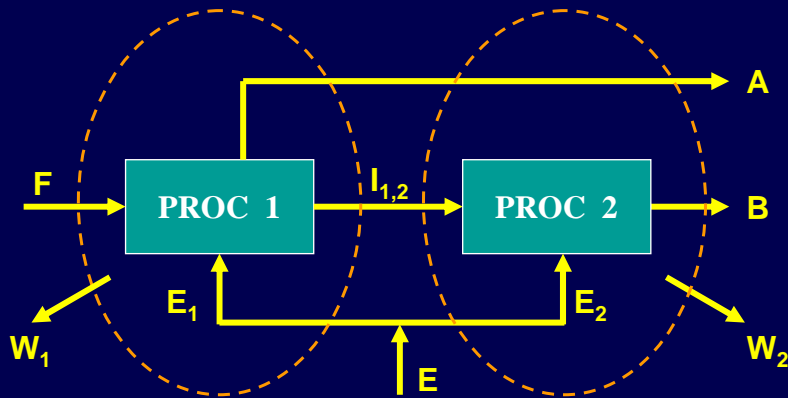
$$V_B = BC_B - C_F FX_B ; Y_B = V_B / (V_A + V_B) ; E_B = Y_B E$$

Indices = E_A/A and E_B/B

GENERAL PRINCIPLES

- Process outputs that do not make a profit should not be made intentionally
- Unavoidable by-products should be considered as waste streams
- Energy costs (or any other production costs) should not be assigned to waste by-products
- Sales revenue from waste by-products should be deducted from feedstock costs

MORE RIGOROUS (AND COMPLEX) FORMULATION



- Energy Allocation Procedure
- Energy Accrual Procedure



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FEATURES OF A RATIONAL ALLOCATION PROCEDURE

- Need a heat and material balance model of the process to track how much energy costs a product attracts before it leaves the plant
- If a product does not make profit, the losses must be distributed among other profit-making products
- Distribution of losses should be pro-rated on the basis of profit
- After distribution of losses, net cost of each waste by-product should be Zero



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ENERGY ACCRUAL PROCEDURE

Total energy accrued for a product i =

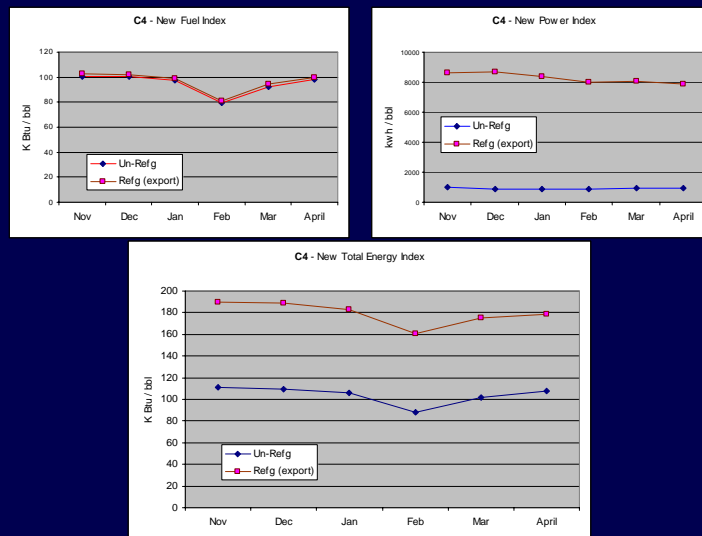
Sum of energy allocated to it from every process unit J through which it passes

$$= \sum Y_{iJ} E_J$$

where E_J = total energy used in process operation J , and Y_{iJ} = fraction of energy use allocated to the product i in process J .










EXAMPLE: EPIs for C₄ by NGL FRACTIONATION (gas + liquid)



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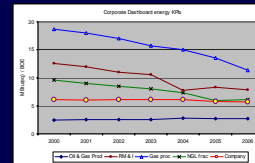
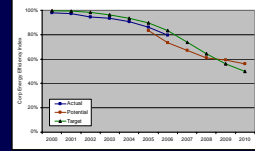
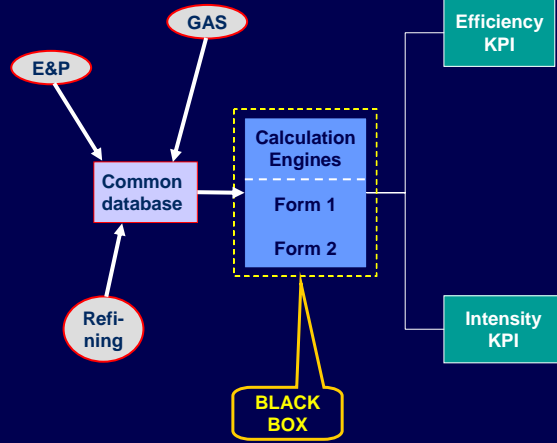
ENERGY INTENSITY COMPARISONS (conventional)

Indices	2005				2004		
							
Total energy consumed (billion GJ)	1.31	1.57	0.90	0.60	0.46	0.45	
Energy Intensity (GJ / tonne)	3.91	3.07	4.07	0.93	6.98	3.85	1.35
Energy Intensity (MMBtu / MBOE)	511	400	531	121	911	502	176

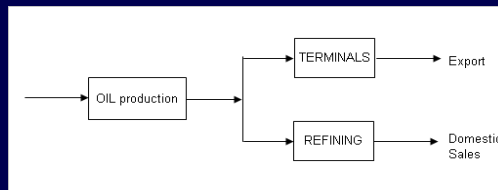
World's Best ?

EXCELLENCE OR LUCK ? ARE WE COMPARING APPLES & ORANGES?

SAME DATA – DIFFERENT PERSPECTIVES



TEST EXAMPLE 1: Refine Higher % of Crude Oil (value-adding)



Basis Data	2000	2005	2010 (estimates)	
			case 1	case 2
Crude oil production, BOE/day	7800	9065	11000	11000
E&P energy cost, cents/BOE	9.7	9.2	8.0	8.0
% Reduction from 2005			13.04	13.04
Refinery feed rate, BOE/day	1198	1534	1800	2200
RMI energy cost, cents/BOE	38	27	24	24
% Reduction from 2005			11.11	11.11
Conventional intensity index				
"Production", BOE/day	8998	10599	12800	13200
Energy Costs, K\$/day	1212	1248	1312	1408
Combined prod cost, c/BOE	13.5	11.8	10.3	10.7
Energy Intensity Index	100	87.4	76.1	79.2
% Reduction from 2005			12.96	9.42
k&A efficiency index				
Actual energy cost, K\$/day	1212	1248	1312	1408
Bus Usual energy cost, K\$/day	1212	1462	1761	1993
Energy Efficiency Index	100	85.4	74.9	74.0
% Reduction from 2005			12.22	13.32

More Oil refined in case 2

Intensity Index gets worse

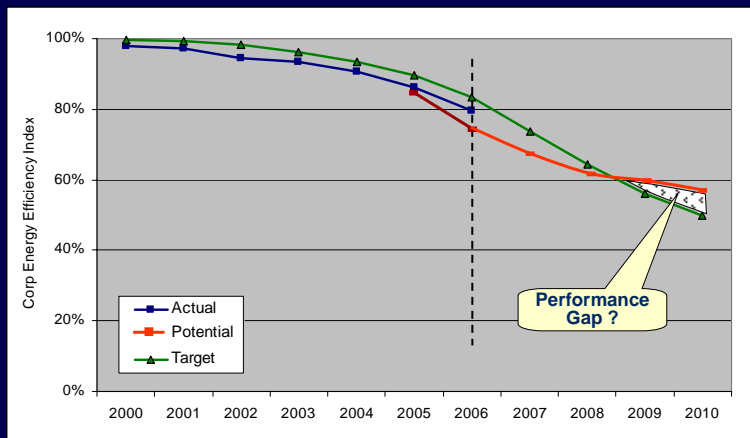
Efficiency Index gets better

TEST EXAMPLE 2: Improve Refinery Profitability (eg. by making more higher-value gasoline vs lower-value Fuel Oil)

Basis Data	Old	New	Comment
Refinery feed rate, MBD	400	400	40 \$/bbl
% gasoline	20	21	80 \$/bbl
% FO	40	39	30 \$/bbl
gasoline revenue, K\$/day	-134086	-140790	
FO revenue, K\$/day	-278205	-271250	
Total revenue, K\$/day	-412290	-412040	
Incremental revenue, K\$/day	0	250.8	operational change only
Energy reqd, BTUe/BOE feed	25000	30000	Intensity index
Actual Energy cost, \$/day	20.0	24.0	2.00 \$/MMBtu
Incremental "profit", K\$/day	0	246.8	
Bus Usual energy cost, \$/day	25.0	29.0	assume no Δ in eff
K&A energy efficiency index	0.80	0.83	
Intensity index change	0	20.0 % (wrong direction, big)	
K&A efficiency index change	0	3.4 % (wrong direction, small)	

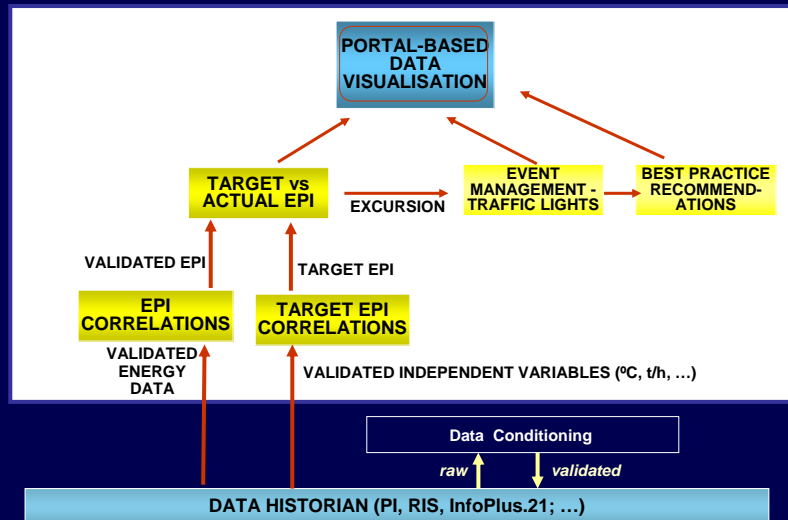
NET REVENUE IMPROVES BY \$196 K/day, BUT Intensity INDEX GETS 20% WORSE !!!
TO BE FAIR, EFFICIENCY INDEX ALSO GETS WORSE (A DEFECT), BUT ONLY BY 3%

ACTUAL OVERALL CORPORATE ENERGY KPI (Confidential Client)



$$\text{Energy Efficiency Index} = \frac{\text{Actual Energy Cost}}{\text{Energy Cost at Baseline Efficiency}}$$

AND FINALLY, WE NEED TO PUT IT ALL TOGETHER



CONCLUSIONS & RECOMMENDATIONS

1. A systematic and consistent methodology has been presented to formulate, report, and use Energy KPIs – for equipment, for process units, for entire plants, and for the company as a whole.
2. Accurate data is essential (more/better instrumentation and data reconciliation software may be needed).
3. Material and energy balance simulation models are required.
4. Primary energy (eg. fuel, purchased power) should be priced at marginal cost; secondary energy (eg. steam, cooling water, cogenerated power) costs should be traced back to primary energy costs via the simulation model.
5. For effective results, a company-wide online Energy Management Software system should be deployed.