



***Practical Applications of Green Engineering***  
Solvent Recovery/Reuse in Pharmaceutical Processes

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US EPA

Expanding Business Value Through Pollution  
Prevention & Sustainable Practices

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San Juan, Puerto Rico



## Outline of Presentation

- Who are we?
- Green Engineering Pharma Project Goals, Status and Next Steps
- GSK Life Cycle Modules and Solvent Decision Support Tool (DST)
- Decision Support Tool (DST)
  - Tool framework, data input, and LCI / Business Models
  - Solvent, Process and Market Data
  - Community data / EJ impacts
  - Case studies (with environmental and economic benefits)



## Who are we?

- Office of Pollution Prevention and Toxics (OPPT)
  - Toxic Substances Control Act (TSCA) and Pollution Prevention Act (PPA)
  - Multimedia
  - Serves as a gatekeeper/guardian to ensure chemical safety
  - Promotes environmental stewardship and sustainability
    - via collaborative programs (e.g. GC, GE, DfE) and educational activities
    - Develops tools and makes information available
  - Collaborates international to address chemicals
  - Consists of five divisions including Economics Exposure & Technology Division (EETD) and Pollution Prevention Division (PPD)
  - GE activities managed by the Chemical Engineering Branch (CEB) of EETD

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## Project Overview

- Targets initially pharmaceutical processes, where large amounts of toxic solvents are used per mass of final product
- Large contributor to environmental footprint is disposal (incineration / cement kilns) of solvents.



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## Project Goals

- Reduce environmental footprint and report measured results
  - Pounds of toxic materials reduced
  - Metric tons of CO<sub>2</sub> and BTUs reduced
  - Pounds of air, water and solid waste emissions reduced
  - Gallons of water and
  - \$ saved.
- Facilitate information exchange on approaches and practices to rest of pharmaceutical sites and other chemical processes



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## Status of Project

- Developed a Solvent Decision Support Tool (DST)
  - GSK Life Cycle module
  - Estimates energy, GHG and emissions to various media
  - Model to estimate savings corresponding to these reductions
- Identified approaches and practices to recover/reuse solvents
- Developed business case studies using available data collected
- Working closely with the regions and ORCR



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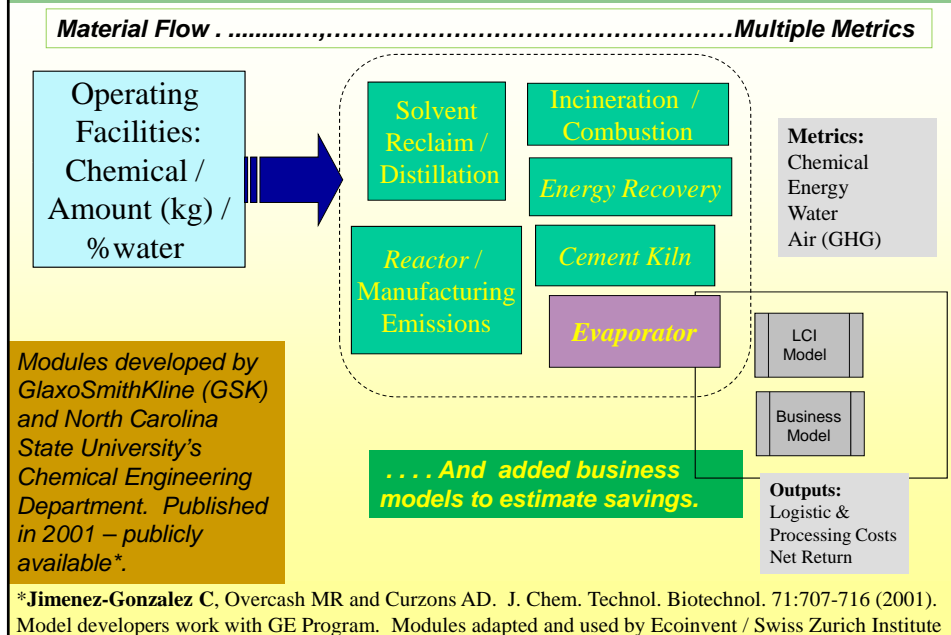
## Next Steps

- Short-Term
  - Work with interested pharmaceutical plants in the regions (e.g. Region 2)
  - Pilot the approaches and practices
  - Apply Solvent Decision Tool using plant-specific data.
- Long-Term
  - Move upstream of the process (e.g. reaction, separation)
  - Stewardship initiative for the broader pharmaceutical industry
  - User-friendly tool for broader use by the Regions and industry
  - Expand to other chemical processes

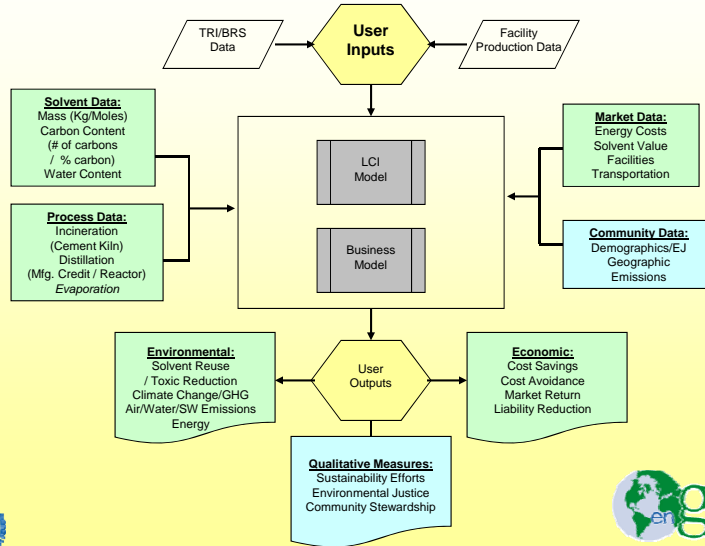


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## Adapted GSK Life Cycle Modules . . .



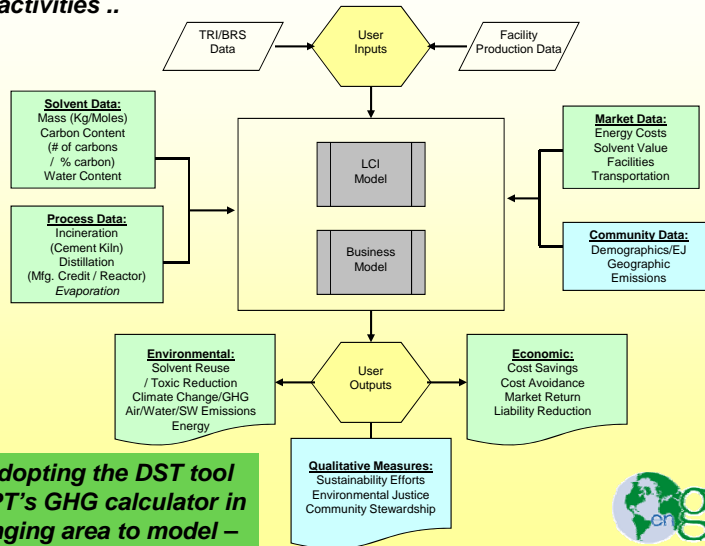
# Solvent Decision Support Tool



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# Solvent Decision Support Tool

**Outside the Box: Concurrent with GE activities ..**



**PPD is adopting the DST tool into OPPT's GHG calculator in a challenging area to model – Materials Management Tab**



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## Solvent Data – Mass & Carbon Balance

**Solvent Data:**  
 Mass  
 (Kg/Moles)  
 Carbon Content  
 (# of carbons  
 / % carbon)  
 Water Content

**TWO VARIABLES: How much Carbon and How much Water**

**Kg in -> Kg out (mass balance)**

**Carbon in -> Carbon out (carbon balance)**

**Water in -> Water out**

**\$\$ in -> \$\$ out**

**Isotainer**

Solvent	Molecular Weight	Chemical Formula	# of Carbons	% Carbon	% Water	Kg in 5000 gallons
Methanol	32	CH <sub>4</sub> O	1	37%	50%	7,481
Tetrahydrofuran	72	C <sub>4</sub> H <sub>8</sub> O	4	67%	25%	12,642
Toluene	92	C <sub>7</sub> H <sub>8</sub>	7	91%	0%	16,477

**What do you do now? (dispose as waste – baseline & worst case)**



**Process change to extend solvent life?**

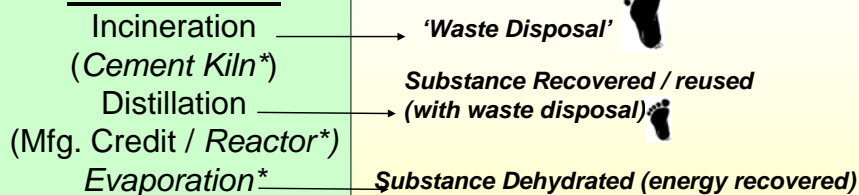
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**DST provides metrics for each process change. (lbs, GHG, energy, \$\$)**

## Process Data – Where Solvents Go . .

**Disposal is worst case scenario – any change will provide numerous benefits**

**Process Data:**



- Toluene (like oil). High Carbon. No Water.
- Tetrahydrofuran (THF) Medium Carbon. Quarter Water.
- Methanol (like water) Low Carbon. Half Water.
- Demonstrate impacts of carbon and water through various processing / unit operations



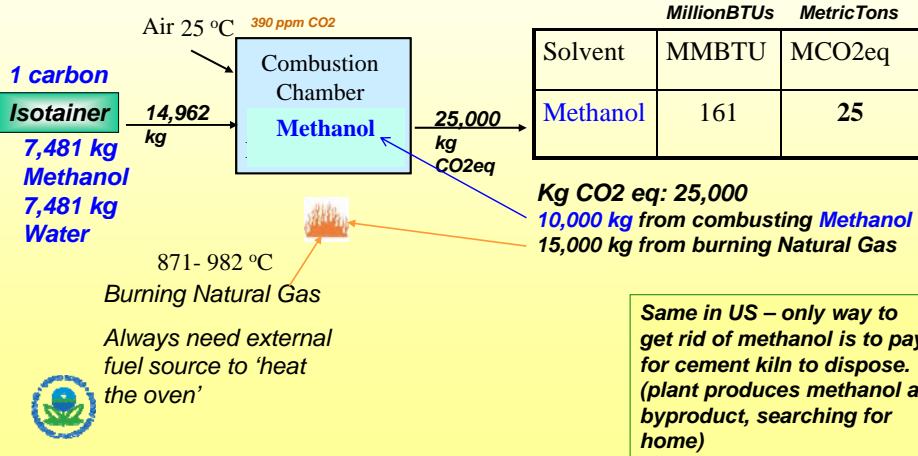
\* Adapting / Developing Models



## Incinerator Module: Methanol (single carbon)

**COMBUSTION!! More Carbon out than in!!! Shipping and Burning Water!!!!**

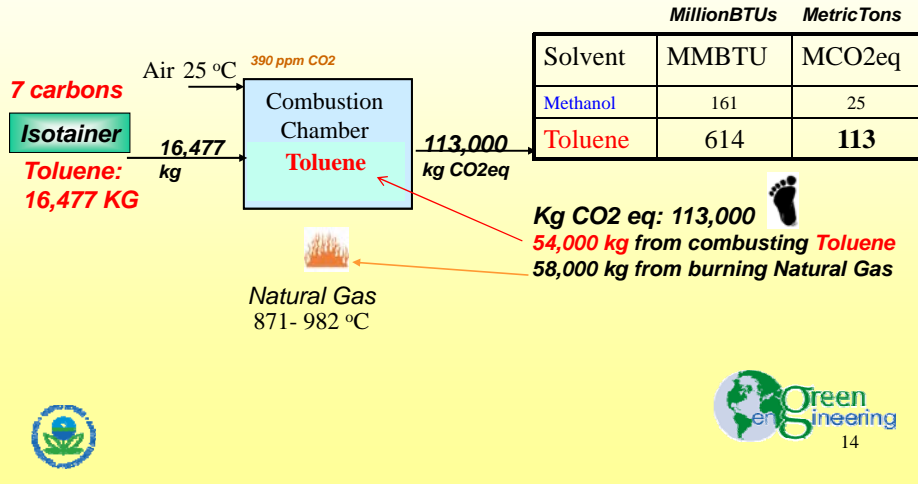
Materials are put in the oven where air containing CO<sub>2</sub> is heated and materials are 'baked' until destroyed. For methanol, energy extended (depleted) to burn water before combusting carbon in solvent.



## Incinerator Module: Toluene (multi-carbon)

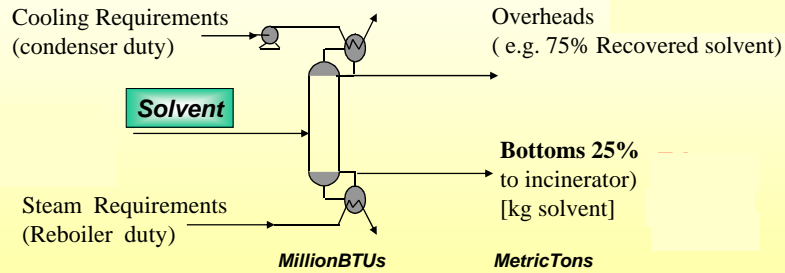
**COMBUSTION!! Even more Carbon out than in!!!**

For Toluene, all energy is extended to combust high carbon material, which is what makes it a good fuel (oil). Largest footprint with energy use and carbon emissions.



## Solvent Distill / Reclaim Module

Solvent is fed into distillation column. Evaporated solvent goes to the top and is recovered. Model default recovery rate is 75%. Heavier components, including water, go to the bottom. Bottoms are typically disposed of as hazardous waste.



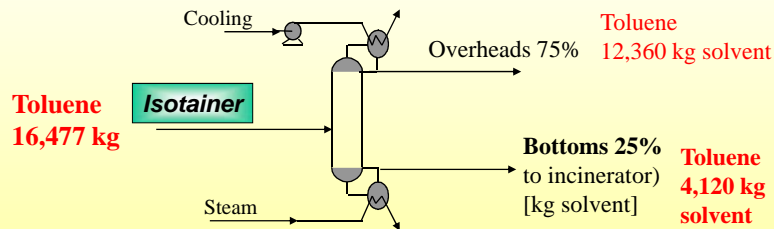
Whenever you distill you have bottoms to contend with . . . Why this makes a difference? Waste can (currently) only be disposed in US with high manifest shipping and processing costs.



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## Toluene – Primary Distillation (Reclamation)

	MillionBTUs	MetricTons
Solvent	MMBTU	MCO2eq
<b>Distill 100%</b>	10.4 steam	1.1



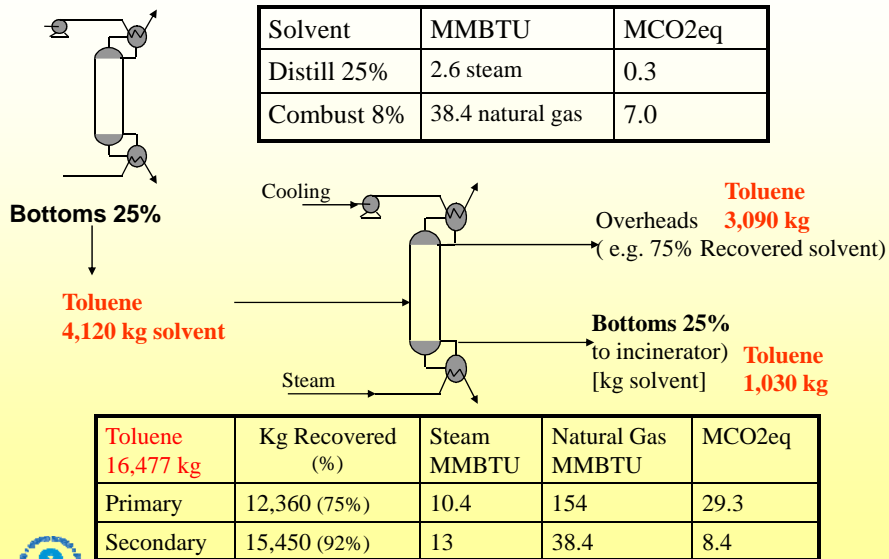
It takes 15 times more Energy in natural gas and generates 25 times CO2eq when combusting 25% (bottoms) then it does to distill 100% with steam.

	MMBTU	MCO2eq
Solvent	MMBTU	MCO2eq
<b>Combust 25%</b>	154 natural gas	28.2



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## Toluene – Secondary Distillation (Reclamation)



Effective bottoms management increases yield and reduces footprint<sup>17</sup>

## Solvent Recovery Module Manufacturing Emissions

- A reused solvent replaces solvent that would have otherwise been purchased. A reused solvent thus avoids disposal and manufacturing emissions.
- Highly processed chemicals, such as THF, have higher manufacturing emissions as compared to basic building block chemicals, such as toluene.
- Estimations of manufacturing emissions (cradle to gate) are similar from different sources. (GSK / Zurich Institute Paper) Currently have manufacturing emissions for all 33 F solvents.



## Toluene – Distillation Manufacturing Emissions

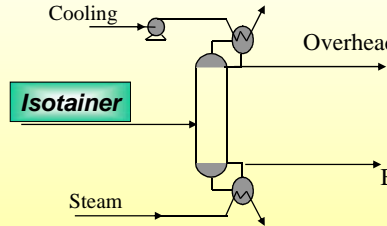
### Distillation Emissions

MMBTU	MCO <sub>2</sub> eq
10.4	1.1

### Manufacturing Emissions

MMBTU	MCO <sub>2</sub> eq
96	14.4

**Toluene**  
16,477 kg



**12,360 kg solvent**  
Recovered \$0.30/lb  
Bill Of Lading (BOL)

**4,120 kg solvent**

MMBTU	MCO <sub>2</sub> eq
154	28.2

**For toluene, energy and GHG is lower to distill then to manufacture, and highest to combust.**



## THF – Distillation Manufacturing Emissions

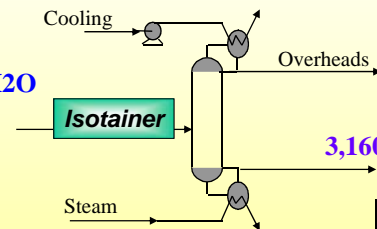
### Distillation Emissions

MMBTU	MCO <sub>2</sub> eq
10.4	1.1
10	1.0

### Manufacturing Emissions

MMBTU	MCO <sub>2</sub> eq
96	14.4
1135	153

**THF & 25% H<sub>2</sub>O**  
12,642 kg  
4,214 kg water  
16,856 kg total



**9,481 kg THF**

Recovered \$1.10/lb  
Bill Of Lading (BOL)

**3,160 kg THF & 4214 kg water\***

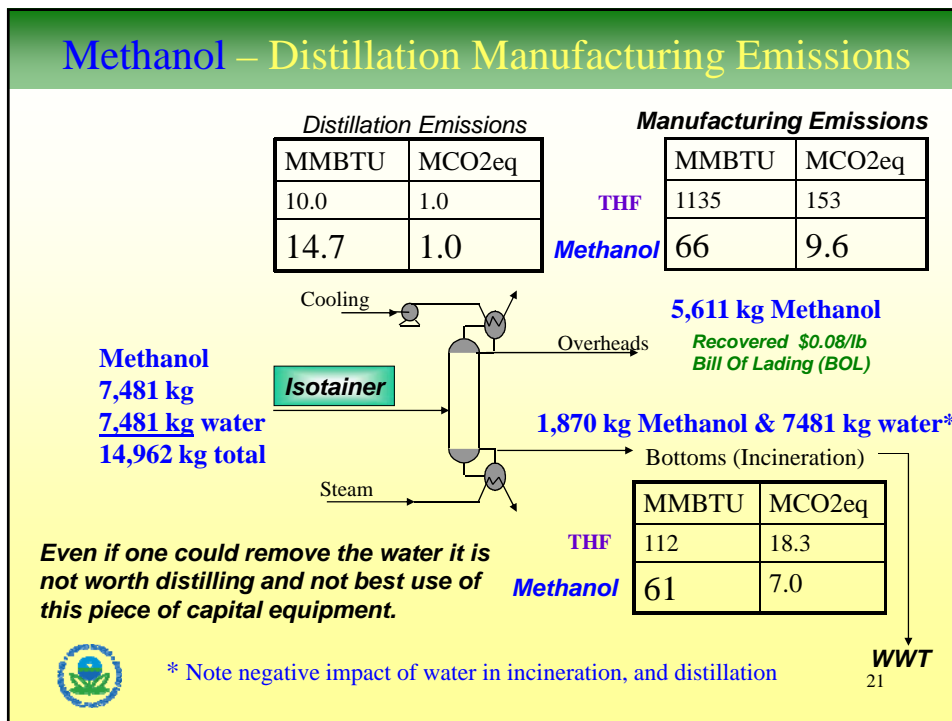
MMBTU	MCO <sub>2</sub> eq
154	28.2
112	18.3

**The high manufacturing emissions and resale cost for recovered THF are so high that they dwarf both distillation and incineration impacts.**



WWT  
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## Methanol – Distillation Manufacturing Emissions



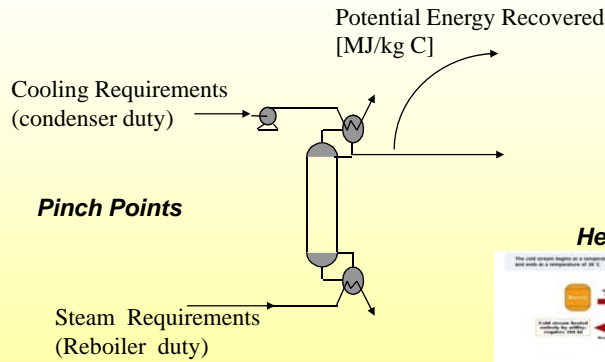
## What to do with the Methanol? What to do with the Water?

- **Methanol Denitrification:** Methanol Institute: Methanol serves as a carbon source for bacterial bugs in Waste Water Treatment Plants (WWTP), accelerating the anaerobic bacteria's conversion of the nitrate to harmless nitrogen gas at a fraction of the cost of nitrate removal. ([www.Methanol.org](http://www.Methanol.org))
- **Raw Material:** Windshield washer fluid; Methyl acetate (produced by esterifying methanol and separating w/ toluene)
- **Chemical Wash:** Methanol 'baths' are common in specialty chemical industry and already use recovered methanol (color)
- **Energy Recovery:**
  - **Miscible:** Most soluble – alcohol / water. Can be used in non- contact heating / cooling in place of water at any dilution
  - **Evaporative Technology:** Can process large amounts of material and operates on 'waste' / recovered steam

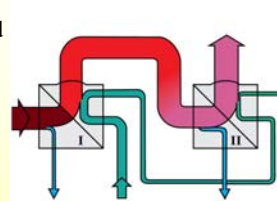


# Distillation – Energy Recovery Opportunities

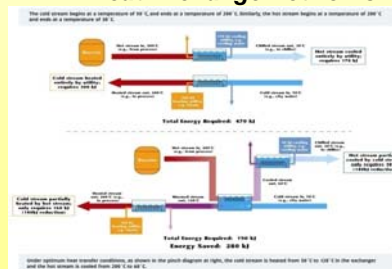
## Energy Recovery opportunities



## Evaporative Technology



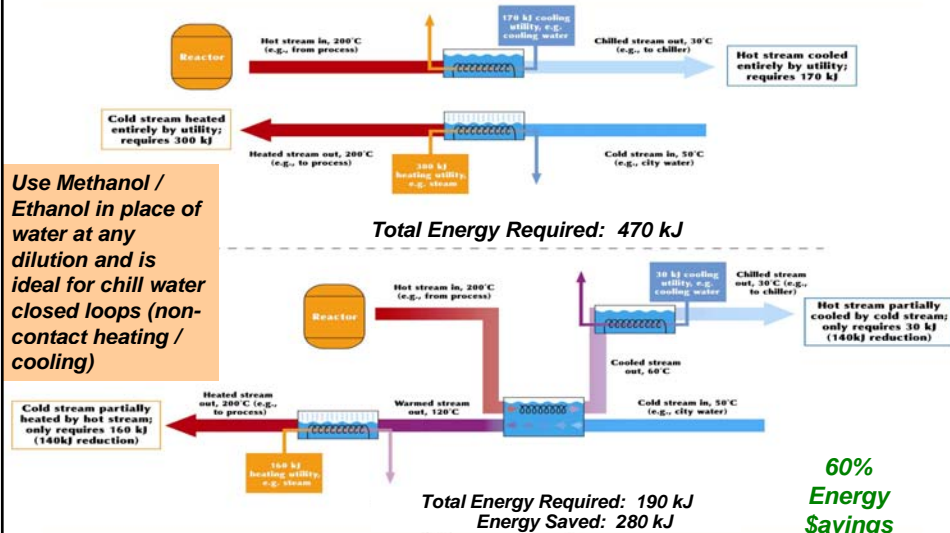
## Heat Exchange Networks



**Distillation LCI module can calculate 'pinch points' for optimum use of recovered energy**

# Heat Exchange Network

The cold stream begins at a temperature of 50 °C, and ends at a temperature of 200 °C. Similarly, the hot stream begins at a temperature of 200 °C and ends at a temperature of 30 °C.



## Energy Recovery Example

### Dow Chemical's Louisiana division energy-savings projects:

*Projects involved more sophisticated thermodynamic "pinch" analysis, which allowed engineers to figure out where to place heat exchangers to capture heat emitted in one part of a chemical process and transfer it to a different part of the process where heat is needed. The first year, 1982, required a total capital investment of \$1.7 million with an average annual return on investment of 173 percent. The second year required a total capital investment of \$2.2 million and a 340 percent return -- a savings of \$7.5 million in the first year and every year after that.*

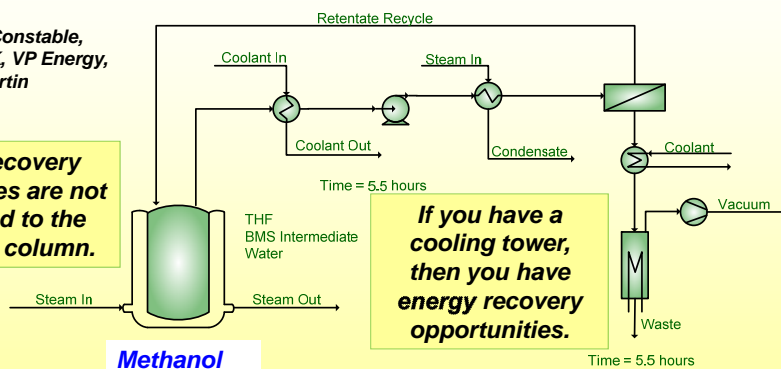


## GE Opportunities: Energy and the UTILITY PLANT

**70% of all energy consumed is for steam and cooling\***

\* David J.C. Constable,  
formerly GSK, VP Energy,  
Lockheed Martin

**Energy recovery opportunities are not just limited to the distillation column.**



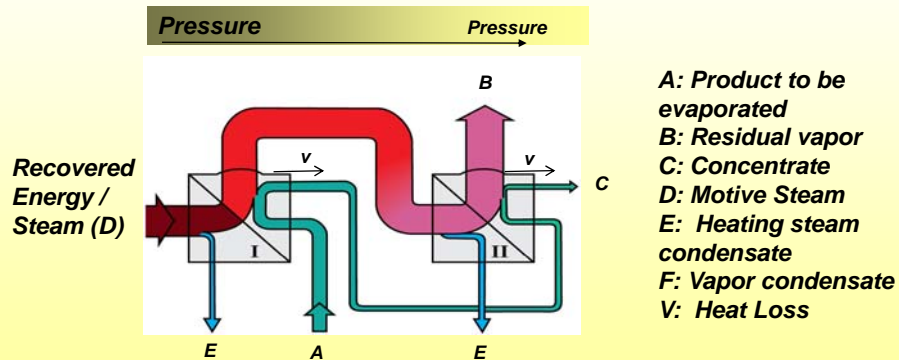
**If you have a cooling tower, then you have energy recovery opportunities.**

A single batch reactor and separation diagram. Methanol is commonly fed to reactor @85%. Energy from this stream can be used to help heat steam in or cool steam out based on its temperature.



## Evaporation – Water removal and Energy Recovery

**Multiple Effect Arrangement:** In a multiple effect evaporation plant, the vapor produced in the first effect by the live steam is not lost to the condenser, but is reutilized as the heating medium of the second effect. This effectively reduced the steam consumption by about 50%.



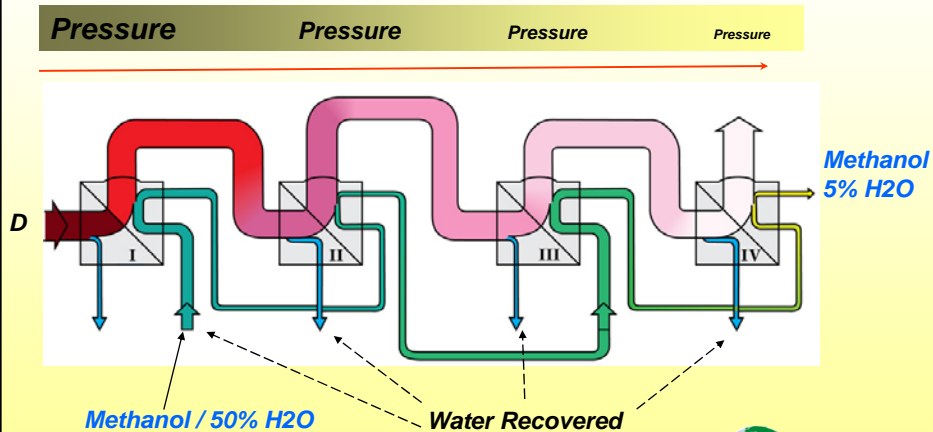
The main advantage of the multi-effect system is the high steam efficiency, which can be as high as 5.5 lbs water evaporated per lb of steam for a six effect system. (Smook, Handbook for Pulp & Paper Technologies)



## Multi-Effect Evaporation: Methanol

### Evaporator with Four Effects

Single effect effectively reduces steam consumption by about 50%. As more effects are added, further steam reductions will follow.



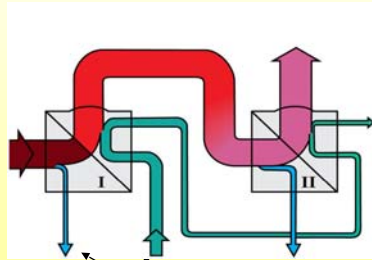
Benefits of concentrated chemical, recovered water and energy saved.



## Evaporation for Tetrahydrofuran (THF) / Energy Recovery

THF evaporated for water removal – 25% to 5%.

Recovered Heat From Distillation



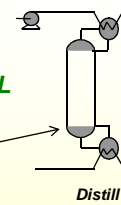
Tetrahydrofuran (THF)  
12,642 kg / 25% H<sub>2</sub>O



Water Recovered

Feedstock  
\$0.10/lb BOL

12642 kg  
THF /  
5% H<sub>2</sub>O



Recovered  
\$1.10/lb  
BOL



## Solvent Recovery Module

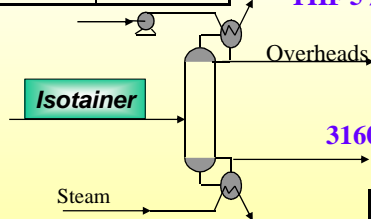
Distillation Emissions

MMBTU	MCO <sub>2</sub> eq
10.4	1.1
10	1.0
12.2	1.3

Manufacturing Emissions

MMBTU	MCO <sub>2</sub> eq
96	14.4
1135	153
1390	188

THF 5%  
16,013 kg THF  
843 kg water  
16,856 kg total



12,009 kg THF  
(9,481 kg recovered at 25%)

3160 kg THF & 843 kg water  
Bottoms (Incineration)

THF 25%  
12,642 kg THF  
4,214 kg water  
16,856 kg total



Toluene  
THF 25%  
THF 5%

MMBTU	MCO <sub>2</sub> eq
154	28.2
112	18.3
110	19.8

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## Market Data – Parameters that effect costs . .

**Market Data:**  
 Energy Costs  
 Solvent Value  
 Facilities  
 Transportation

### Where recovered? In our out of manufacturing? Manifest versus Bill of Lading (BOL)?

Business case models:

- Logistics
  - US Waste / Manifest (\$0.14 / lb)
  - US Substance / BOL (\$0.12 / lb),
  - Puerto Rico Substance / BOL (\$0.01 lb)
- Processing (waste disposal, batch distill)
- Market Value (Virgin/SPEC, recovered, blend)



## Where Recovered?? Solvent Waste Stream (#6)

### Material Streams and Descriptions

ID#	Description
1	Raw Material Solvent Feed to Batch Reactor
2	Pharmaceutical Products
3	Solvent emissions to air pollution control unit (APC)
4	Solvent washdown from Separation batch reactor
5	Solvent washdown from APC regeneration cycle

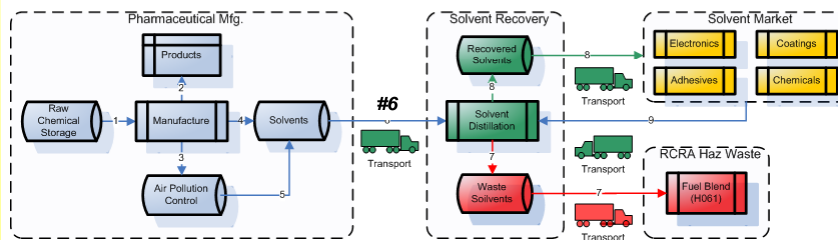
ID#	Description
6	Discarded solvent material (Crude Feedstock)
7	Solvent Bottoms (Waste Solvent)
8	Solvent Distillate (Recovered Toluene for Resale)
9	Discarded solvent material (Next Generation)

### Material Streams and Economics (Case 2)

ID#	Description	Cost Component	Mass (Pound)	Unit Price (Pound)	Ext Price (Pound)
6	Crude Feedstock	Transport	36,192	\$ (0.120)	\$ (4,344)
6	Crude Feedstock (50% Toluene)	Processing	18,096	\$ (0.150)	\$ (2,714)
7	Distillation Bottoms	Disposal	22,620	\$ (0.017)	\$ (375)
8	Recovered Solvent	Market Resale	13,572	\$ 0.300	\$ 4,072
				Net Total	\$ (3,361)
				Per Gallon	\$ (0.67)

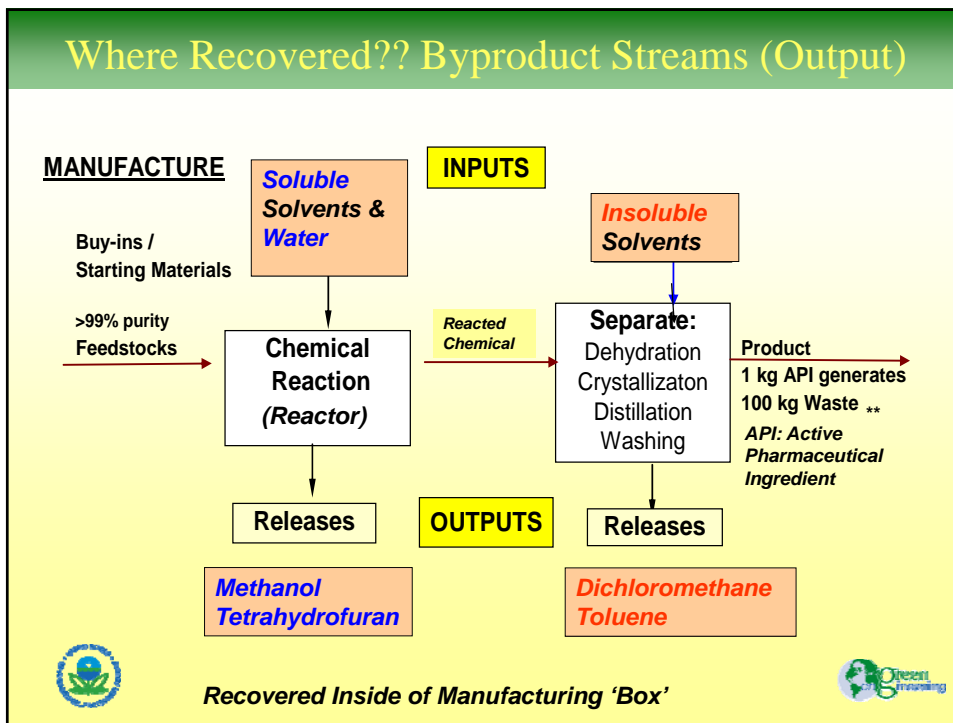
### Crude Feedstock Composition (ID # 6)

Material	Conc.	SG
Toluene	50.0%	0.88
Methanol/Ethanol	30.0%	0.79
Ethyl-Acetate	10.0%	0.90
Water	5.0%	1.00
Solids	5.0%	1.00
<b>Total</b>	<b>100.0%</b>	<b>0.87</b>

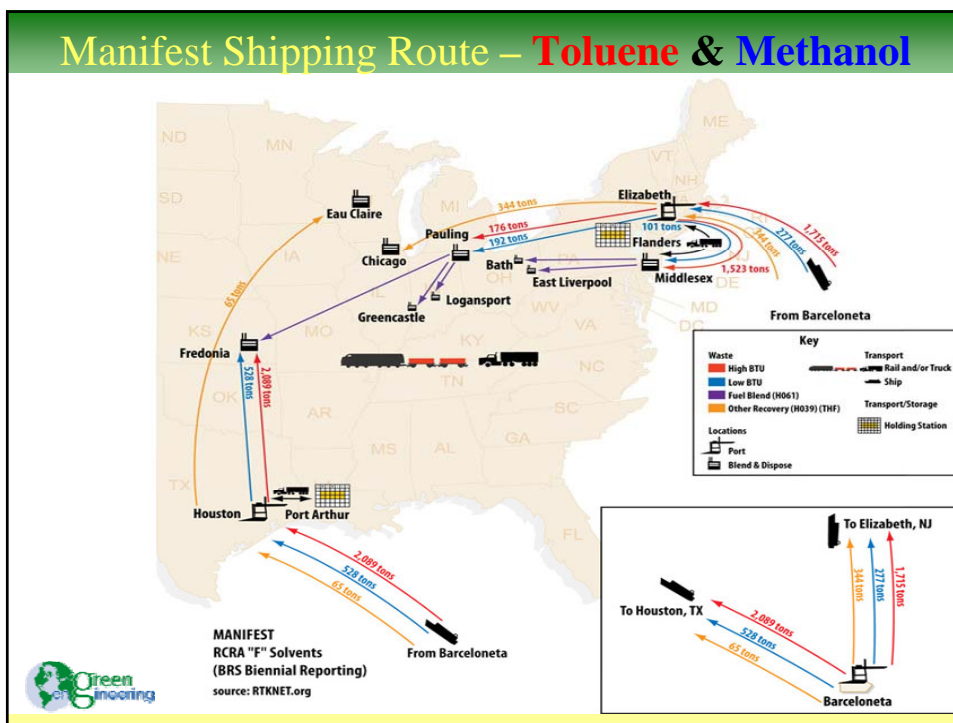


Recovered Outside of Manufacturing 'Box'

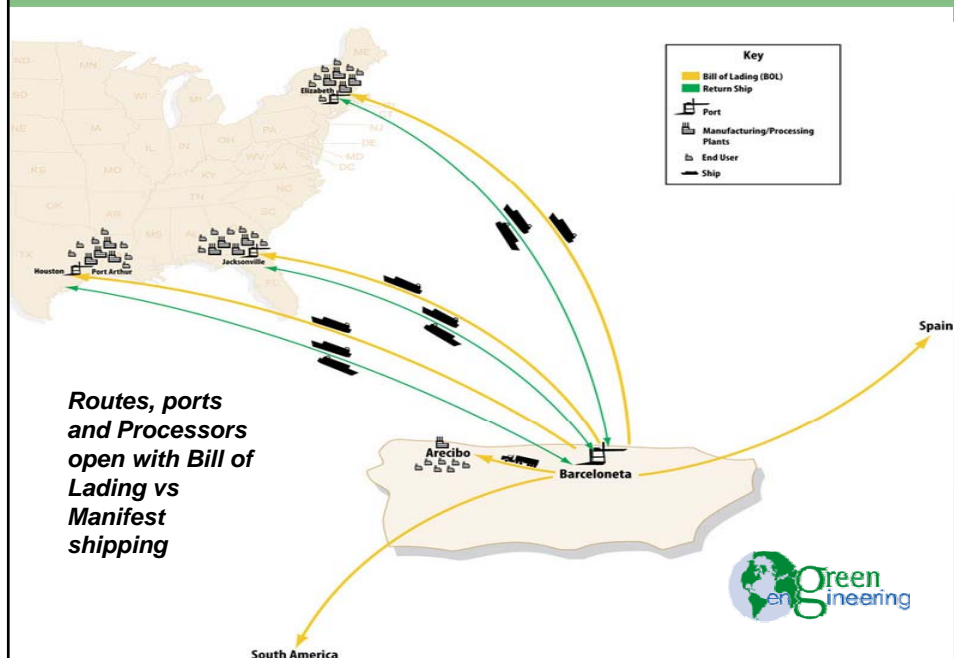
## Where Recovered?? Byproduct Streams (Output)



## Manifest Shipping Route – Toluene & Methanol



## Bill of Lading (BOL) Shipping Routes and Processors



## Toluene Business Model - Benefits Table Worksheet

**Toluene 36,192 lbs (5000 Gallons)**

Recovered: \$0.30 / lb

SPEC: \$0.40 / lb

**BOL Houston: \$0.12**

**BOL Puerto Rico: \$0.01**

	Waste / US - Manifest		Houston - Bill of Lading (BOL)		Puerto Rico - Bill of Lading (BOL)	
	Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Prim/Secondary Distill Recovered Substance	Primary Distill Recovered Substance	Prim/Sec Distill Recovered Substance
<b>LOGISTICS</b>	(\$5,110)	(\$5,110)	(\$4,343)	(\$4,343)	(\$400)	(\$400)
\$/lb	(\$0.14)	(\$0.14)	(\$0.12)	(\$0.12)	(\$0.01)	(\$0.01)
<b>PROCESING</b>	(\$600)	(\$9,198)	(\$5,578)	(\$5,476)	(\$5,578)	(\$4,476)
\$/lb	(\$0.02)	(\$0.25)	(\$0.15)	(\$0.15)	(\$0.15)	(\$0.15)
Isotainer						
<b>MARKET VALUE</b>	-	\$8,143	\$8,143	\$9,989	\$8,143	\$9,989
yield&conc \$/lb		\$0.23	\$0.23	\$0.28	\$0.23	\$0.28
<b>NET RETURN</b>	(\$5,710)	(\$6,165)	(\$1,780)	\$169	\$2,164	\$4,112
\$/lb	(\$0.16)	(\$0.17)	(\$0.08)	\$0.00	\$0.06	\$0.12
<b>\$ / Gallon</b>	(\$1.14)	(\$1.23)	(\$0.36)	\$0.03	\$0.43	\$3.29
Advantage to Fuel	(\$0.09)		\$0.79	\$1.18	\$1.57	\$4.43

Current scenario in column 1 – waste fuel. Column 2 – primary distill – demonstrates why cost prohibitive to recover as waste (Manifest).



BOL: (cost per isotainer for same material)  
 Logistics – 2 cents more a pound (\$5110 vs \$4343)  
 – 10 cents more a pound (\$9198 vs \$5578)



## Toluene Business Model - Benefits Table Worksheet

**Toluene 36,192 lbs (5000 Gallons)**

Recovered: \$0.30 / lb

**SPEC: \$0.40 / lb**

	Waste / US - Manifest		Houston - Bill of Lading (BOL)		Houston BOL	Puerto Rico
	Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Prim/Secondary Distill Recovered Substance	use / reuse Filter Recovered Substance	use / reuse Filter Recovered Substance
<b>LOGISTICS</b>	(\$5,110)	(\$5,110)	(\$4,343)	(\$4,343)	(\$4,343)	(\$400)
\$/lb	(\$0.14)	(\$0.14)	(\$0.12)	(\$0.12)	(\$0.12)	(\$0.01)
<b>PROCESING</b>	(\$600)	(\$9,198)	(\$5,578)	(\$5,476)		
\$/lb	(\$0.02)	(\$0.25)	(\$0.15)	(\$0.15)		
Isotainer						
<b>MARKET VALUE</b>	-	\$8,143	\$8,143	\$9,989	\$10,858	\$10,858
yield&conc \$/lb		\$0.23	\$0.23	\$0.28	\$0.30	\$0.30
<b>NET RETURN</b>	(\$5,710)	(\$6,165)	(\$1,780)	\$169	\$6,514	\$10,458
\$/lb	(\$0.16)	(\$0.17)	(\$0.08)	\$0.00	\$0.18	\$0.29
<b>\$/ Gallon</b>	(\$1.14)	(\$1.23)	(\$0.36)	\$0.03	\$1.30	\$2.09
Advantage to Fuel		(\$0.09)	\$0.79	\$1.18	\$2.44	\$3.23

*Use / Reuse – Some of the toluene captured could be put directly back onto the market without any distillation / reclamation. Use / reuse activities include filtering, where a substance can be lightly processed and reused for its original intention. (amanda will cover later)*

*Though recognized limited markets, the returns are attractive enough to seek out these opportunities.*

## Toluene Business Model - Benefits Table Worksheet

**Toluene 36,192 lbs (5000 Gallons)**

Recovered: \$0.30 / lb

**SPEC: \$0.40 / lb**

	Waste / US - Manifest		Houston - Bill of Lading (BOL)		Houston - Bill of Lading (BOL)	
	Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Prim/Secondary Distill Recovered Substance	Prim/Sec Distill SPEC Substance	Prim/Sec Distill SPEC Substance Return Boat
<b>LOGISTICS</b>	(\$5,110)	(\$5,110)	(\$4,343)	(\$4,343)	(\$4,343)	(\$3,475)
\$/lb	(\$0.14)	(\$0.14)	(\$0.12)	(\$0.12)	(\$0.12)	(\$0.10)
<b>PROCESING</b>	(\$600)	(\$9,198)	(\$5,578)	(\$5,476)	(\$5,476)	(\$5,476)
\$/lb	(\$0.02)	(\$0.25)	(\$0.15)	(\$0.15)	(\$0.15)	(\$0.15)
Isotainer						
<b>MARKET VALUE</b>	-	\$8,143	\$8,143	\$9,989	\$13,319	\$13,319
yield&conc \$/lb		\$0.23	\$0.23	\$0.28	\$0.37	\$0.37
<b>NET RETURN</b>	(\$5,710)	(\$6,165)	(\$1,780)	\$169	\$3,499	\$4,367
\$/lb	(\$0.16)	(\$0.17)	(\$0.08)	\$0.00	\$0.09	\$0.12
<b>\$/ Gallon</b>	(\$1.14)	(\$1.23)	(\$0.36)	\$0.03	\$0.70	\$0.87
Advantage to Fuel		(\$0.09)	\$0.79	\$1.18	1.84	2.02

**Other Scenarios:**

- Waste Treatment on Island (no US disposal costs and transport)
- Bottoms are used on site as fuel (no disposal costs)
- Use/Reuse: toluene filtered, BOL, no wastes

**Return SPEC:**

**\$913,000 for  
210 isotainers of  
Toluene**

# Tetrahydrofuran Business Model - Benefits Table

**Tetrahydrofuran (THF) @25%water** (5000 gallons)

Recovered (<500 ppm H2O) \$1.10 / lb  
 Feedstock 95%/5% Water \$0.10 / lb

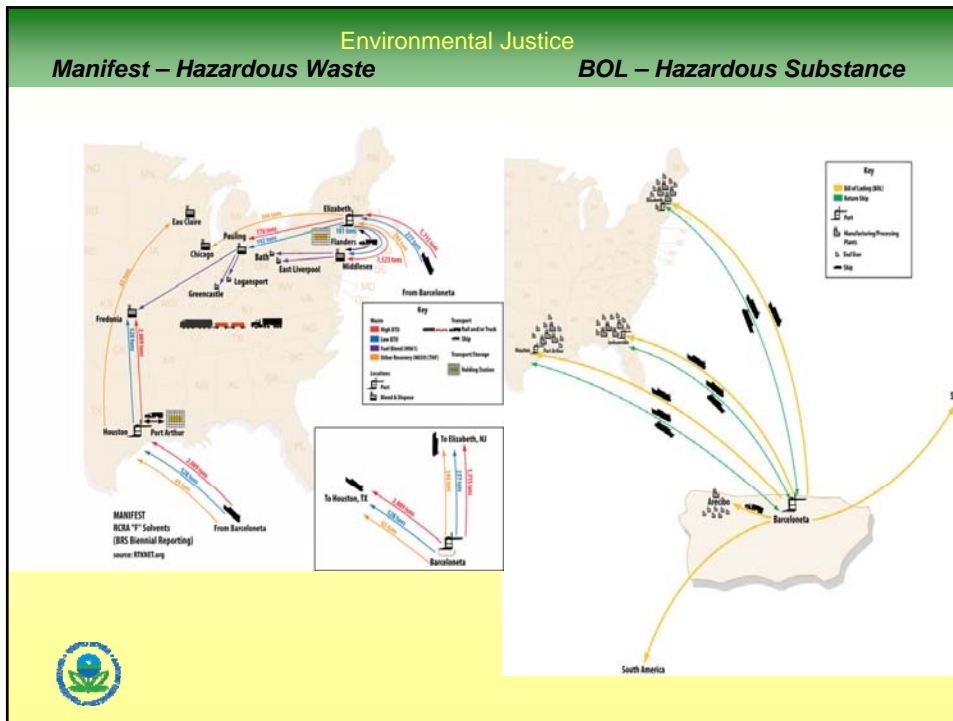
	Waste / US - Manifest		Houston - Bill of Lading (BOL)			Puerto Rico
	Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Evap 5% Distill Recovered Substance	Evap 5% Distill Recovered Substance	Evap 5% Distill Recovered Substance
<b>LOGISTICS</b>						
\$/lb	(\$5,110)	(\$5,110)	(\$4,343)	(\$4,343)	(\$3,475)	(\$400)
	(\$0.14)	(\$0.14)	(\$0.12)	(\$0.12)	(\$0.10)	(\$0.01)
<b>PROCESSING</b>						
\$/lb	(\$600)	(\$11,704)	(\$9,415)	(\$11,766)	(\$11,766)	(\$11,766)
	(\$0.02)	(\$0.31)	(\$0.25)	(\$0.31)	(\$0.31)	(\$0.31)
Isotainer						
<b>MARKET VALUE</b>						
yield&conc \$/lb	-	\$23,597	\$23,597	\$29,890	\$29,890	\$29,890
		\$0.62	\$0.62	\$0.62	\$0.62	\$0.62
<b>NET RETURN</b>						
\$/lb	(\$5,710)	\$6,784	\$9,838	\$13,780	\$14,649	\$17,728
	(\$0.16)	(\$0.17)	\$0.26	\$0.36	\$0.38	\$0.46
<b>\$ / Gallon</b>						
Advantage to Fuel	(\$1.14)	\$1.36	\$1.97	\$2.76	\$2.93	\$3.54
		\$0.21	\$0.83	\$1.61	1.79	\$2.40

### Evap/Distill:

**\$311,000 for 21 isotainers of Toluene**

**1000 gallons water recovered per isotainer**

*With high costs of THF any recovery method does provide. Evap / Distill provides greatest return.*



## Toluene Business Model – Benefits Table Worksheet

**Toluene 36,192 lbs** (5000 gallons)

Recovered: \$0.30 / lb

SPEC: \$0.40 / lb

		Waste / US - Manifest		Houston - Bill of Lading (BOL)	
		Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Prim/Secondary Distill Recovered Substance
<b>LOGISTICS</b>	\$/lb	(\$5,110) (\$0.14)	(\$5,110) (\$0.14)	(\$4,343) (\$0.12)	(\$4,343) (\$0.12)
<b>PROCESING</b>	\$/lb	(\$600) (\$0.02)	(\$9,198) (\$0.25)	(\$5,578) (\$0.15)	(\$5,476) (\$0.15)
Isotainer					
<b>MARKET VALUE</b>	yield&conc \$/lb	-	\$8,143 \$0.23	\$8,143 \$0.23	\$9,989 \$0.28
<b>NET RETURN</b>	\$/lb	(\$5,710) (\$0.16)	(\$6,165) (\$0.17)	(\$1,780) (\$0.08)	\$169 \$0.00
<b>\$ / Gallon</b>	Advantage to Fuel	(\$1.14)	(\$1.23) (\$0.09)	(\$0.36) \$0.79	\$0.03 \$1.18

TOLUENE 100%

16,477 kg / 5000 Gallons Isotainer

KG material recovered	0	12,360	15,450
Manufacturing Credit MCO2 eq		-14.4	-18
Processing MCO2eq	113	29	8
<b>TOTAL Metric Ton CO2eq</b>	<b>113</b>	<b>14.6</b>	<b>-10</b>
Manufacturing Credit MMBTUs		-96	-120
Processing MMBTUs	370	164	51.4
<b>Total Million BTUs</b>	<b>370</b>	<b>68</b>	<b>-68.6</b>



## THF Business Model – Benefits Table Worksheet

**Tetrahydrofuran (THF) @25%water** (5000 gallons)

Recovered (<500 ppm H2O) \$1.10 / lb

Feedstock 95%/5% Water \$0.10 / lb

		Waste / US - Manifest		Houston - Bill of Lading (BOL)	
		Fuel Baseline Waste	Primary Distill Recovered Waste	Primary Distill Recovered Substance	Evap 5% Distill Recovered Substance
<b>LOGISTICS</b>	\$/lb	(\$5,110) (\$0.14)	(\$5,110) (\$0.14)	(\$4,343) (\$0.12)	(\$4,343) (\$0.12)
<b>PROCESING</b>	\$/lb	(\$600) (\$0.02)	(\$11,704) (\$0.31)	(\$9,415) (\$0.25)	(\$11,766) (\$0.31)
Isotainer					
<b>MARKET VALUE</b>	yield&conc \$/lb	-	\$23,597 \$0.62	\$23,597 \$0.62	\$29,890 \$0.62
<b>NET RETURN</b>	\$/lb	(\$5,710) (\$0.16)	\$6,784 (\$0.17)	\$9,838 \$0.26	\$13,780 \$0.36
<b>\$ / Gallon</b>	Advantage to Fuel	(\$1.14)	\$1.36 \$0.21	\$1.97 \$0.83	\$2.76 \$1.61

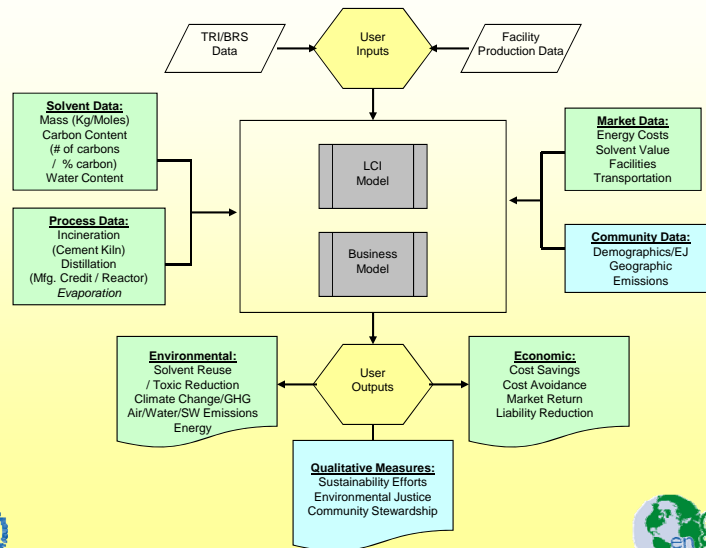
Tetrahydrofuran (THF) 25% H2O

16,856 kg / 5000 Gallons Isotainer

KG material recovered	0	9,481	12,010
Manufacturing Credit MCO2 eq		-153	-194
Processing MCO2eq	66	8.6	11
<b>TOTAL Metric Ton CO2eq</b>	<b>66</b>	<b>-144.4</b>	<b>-183</b>
Manufacturing Credit MMBTUs		-1135	-1438
Processing MMBTUs	370	122	155
<b>Total Million BTUs</b>	<b>370</b>	<b>-1013</b>	<b>-1283</b>



## Solvent Decision Support Tool



## Summary

- Do as much on island as possible . . including processing, water removal and use / reuse.
- Devise different treatment strategies for solvent types such as soluble methanol and insoluble toluene
- Manage bottoms / wastes material minimizing materials that are disposed.
- Apply DST to assess best process changes and concurrent economic and environmental benefits
- Trace solvents streams to point of usage to determine best opportunities to reduce their use and/or extend solvent life
- Waste → Product. Cost → Net Return.

## REFERENCE NOT PART OF PRESENTATION

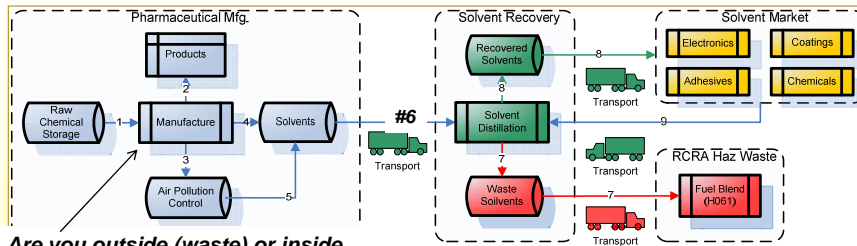
Reference / question slides



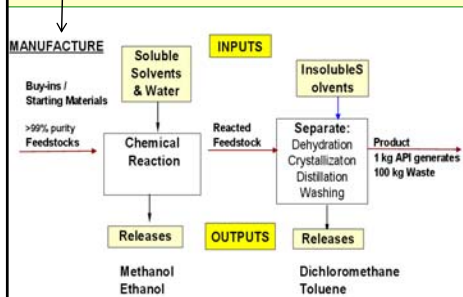
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## Final thought .. When is it Waste and When is it By-Product?

Baseline: Collection at #6 as mixed waste stream. (RCRA reporting, cost Prohibitive to Recover.)



Are you outside (waste) or inside (byproduct) the manufacturing box?

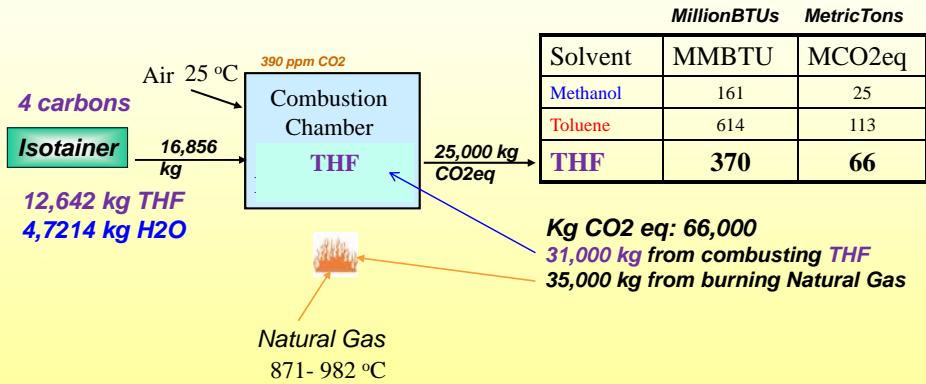


Under the Inventory Update Rule (IUR), a material recovered for commercial use (OUTPUTS) may be required to be reported as a listed substance.

The only one that can answer this question is you - - but we can help you get to that answer and demonstrate why it is worth the trip! ;-)

## Solvent Incinerator Module: Tetrahydrofuran (THF)

For THF, part of energy is extended to combust water and other portion to combust carbon materials. High recovered sale costs and manufacturing emissions provides multiple benefits to extend life vs. disposal.



## Evaporation for Soluble Solvents / Energy Recovery

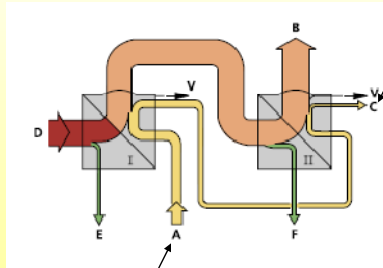
### 1. Multiple Effect Arrangement

In a multiple effect evaporation plant, the vapour produced in the first effect by the live steam is not lost to the condenser, but is reutilized as the heating medium of the second effect. This effectively reduces the steam consumption by about 50%.

As this principle is repeated, further steam reductions follow. **Methanol / THF / 5% H2O**



**Recovered Heat From Distillation**



- A product to be evaporated
- B residual vapour
- C concentrate
- D motive steam
- E heating steam condensate
- F vapour condensate
- V heat loss

Heat flow diagram of a double-effect, directly heated evaporator

**Methanol / 50% H2O & THF @ 75%**



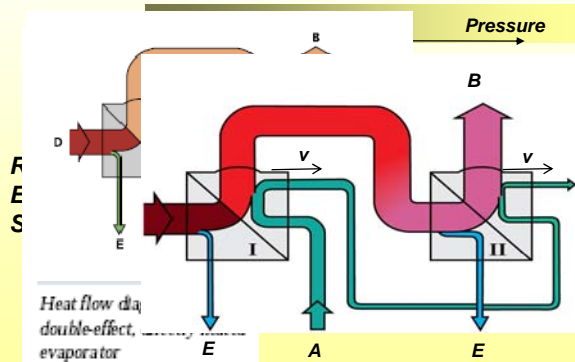
**Double benefits of purer solvent and reduced heating load**

**Incidental Processing – out of RCRA jurisdiction**

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## Evaporation – Water removal and Energy Recovery

**Multiple Effect Arrangement:** In a multiple effect evaporation plant, the vapour produced in the first effect by the live steam is not lost to the condenser, but is reutilized as the heating medium of the second effect. This effectively reduced the steam consumption by about 50%.



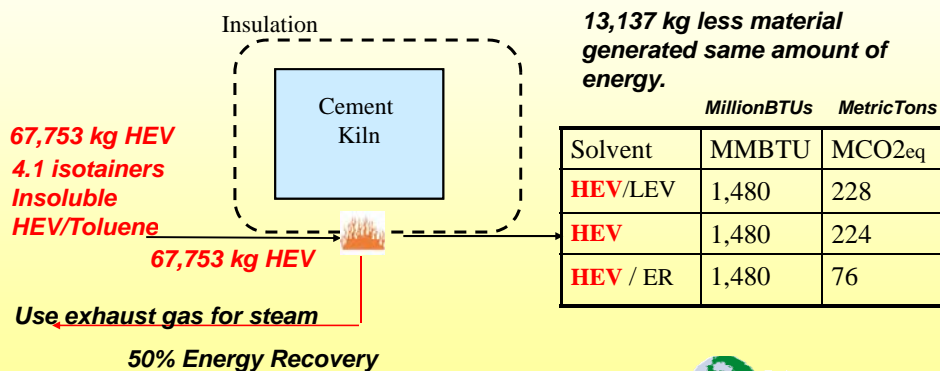
**A:** Product to be evaporated  
**B:** Residual vapor  
**C:** Concentrate  
**D:** Motive Steam  
**E:** Heating steam condensate  
**F:** Vapour condensate  
**V:** Heat Loss

The main advantage of the multi-effect system is the high steam efficiency, which can be as high as 5.5 lbs water evaporated per lb of steam for the sextuplet system. (Smook, Handbook for Pulp & Paper Technologies)



## Cement Module (Adaption in progress)

Solvents are used as Fuel to power cement kiln.



13,137 kg less material generated same amount of energy.

67,753 kg HEV  
 4.1 isotainers  
 Insoluble  
 HEV/Toluene

67,753 kg HEV

Use exhaust gas for steam

50% Energy Recovery



Recovered energy can be used to preheat the HEV generating further savings

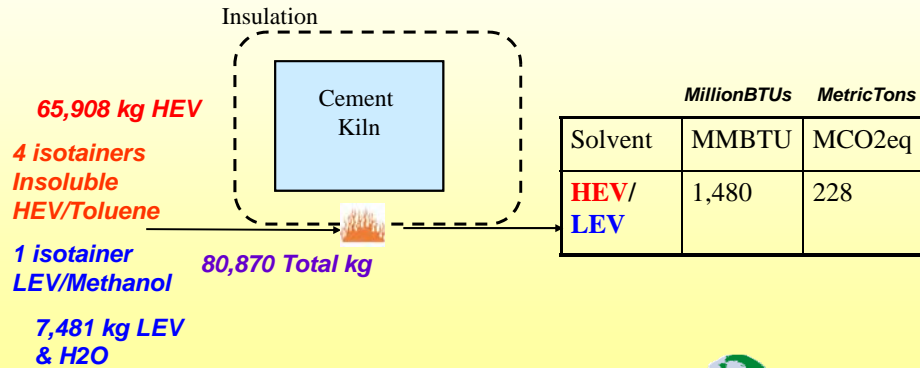


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## Cement Module (Adaption in progress)

*Solvents are used as Fuel to power cement kiln.*

*Common practice is to blend high energy value (HEV) with low energy value (LEV) solvents are used as Fuel to power cement kiln. (HO61)*



## Methanol Business Case (needs updating)

