

Automating the Sustainability Metrics Approach

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BRIDGES to Sustainability™



2004 AIChE Spring Meeting, New Orleans

What is BRIDGES?

- A non-profit research organization
- An educational entity
- A confidential ally / corporate adviser

Integrated, interdisciplinary approach

focusing on

Implementing Sustainability

Metrics Development at BRIDGES



1999

1999 DOE / AIChE

Initiated project with CWRT
Sustainability Metrics Workgroup

Metrics Development at BRIDGES




1999	DOE / AIChE	Initiated project with CWRT Sustainability Metrics Workgroup
2000	Interface Carpets, Formosa Plastics, Owens Corning	Applied CWRT metrics to three companies
2000	45 industry/govt participants	Sustainability Metrics Workshop to critique approach

Metrics Development at BRIDGES




- | | | |
|------|-------------------|---|
| 2001 | DOE / AIChE / SRI | Developed metrics for 50+ chemical processes using PEP data |
| 2001 | DOE / AIChE | “Practical Minimum Energy” as baseline for energy metrics |

Metrics Development at BRIDGES



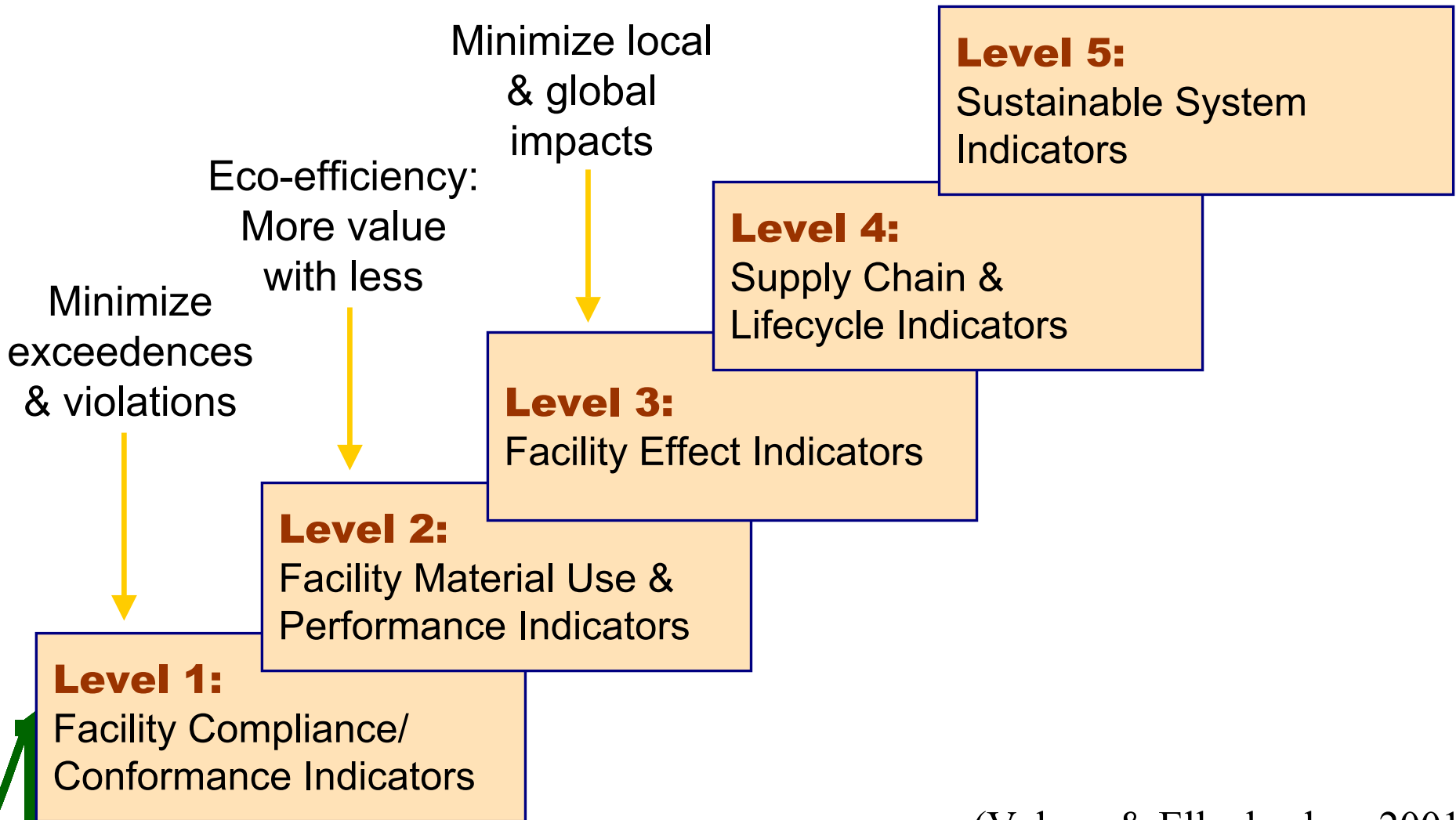
	1999	2000	2001	2002
2001	DOE / AIChE / SRI		Developed metrics for 50+ chemical processes using PEP data	
2001	DOE / AIChE		“Practical Minimum Energy” as baseline for energy metrics	
2002	EPA / GCHSRC		Linked Sustainability Metrics with Total Cost Assessment	
2002	BRIDGES		Initiated development of BRIDGESworks™ Metrics software	

Metrics Development at BRIDGES



	1999	2000	2001	2002	present
2003	The Stanley Works				Pilot metrics for Board Meeting (with <i>convergence consulting</i>)
2003	NSF / Caterpillar				Pilot metrics for product design
2004	The Stanley Works				Expansion of metrics project to Asia, upstream and downstream
2004	AICHe / IfS				Partnership intent: develop educational software, case studies, industry pilots, markets

Evolution of Environmental Metrics



(Veleva & Ellenbecker, 2001)

Evolution of Environmental Metrics

Broader impacts:
time, place, value, resources

Involve suppliers &
customers

Level 5:
Sustainable System
Indicators

Level 4:
Supply Chain &
Lifecycle Indicators

Level 3:
Facility Effect Indicators

Level 2:
Facility Material Use &
Performance Indicators

Level 1:
Facility Compliance/
Conformance Indicators

(Veleva & Ellenbecker, 2001)

Uses for Sustainability Metrics

- Support internal decision-making
 - Evaluate alternatives (technologies, raw materials.....)
 - Identify improvement options
 - Evaluate acquisitions and suppliers
 - Evaluate R&D alternatives / innovations
- Track performance
- Stakeholder communication

Uses for Sustainability Metrics

- Support internal decision-making
 - Evaluate alternatives (technologies, raw materials)
 - Identify risks
 - Evaluate opportunities
 - Evaluate R&D alternatives / innovations
- Track performance
- External reporting

Produce *insights* to
broad range of players

Produce *insights* to broad range of players

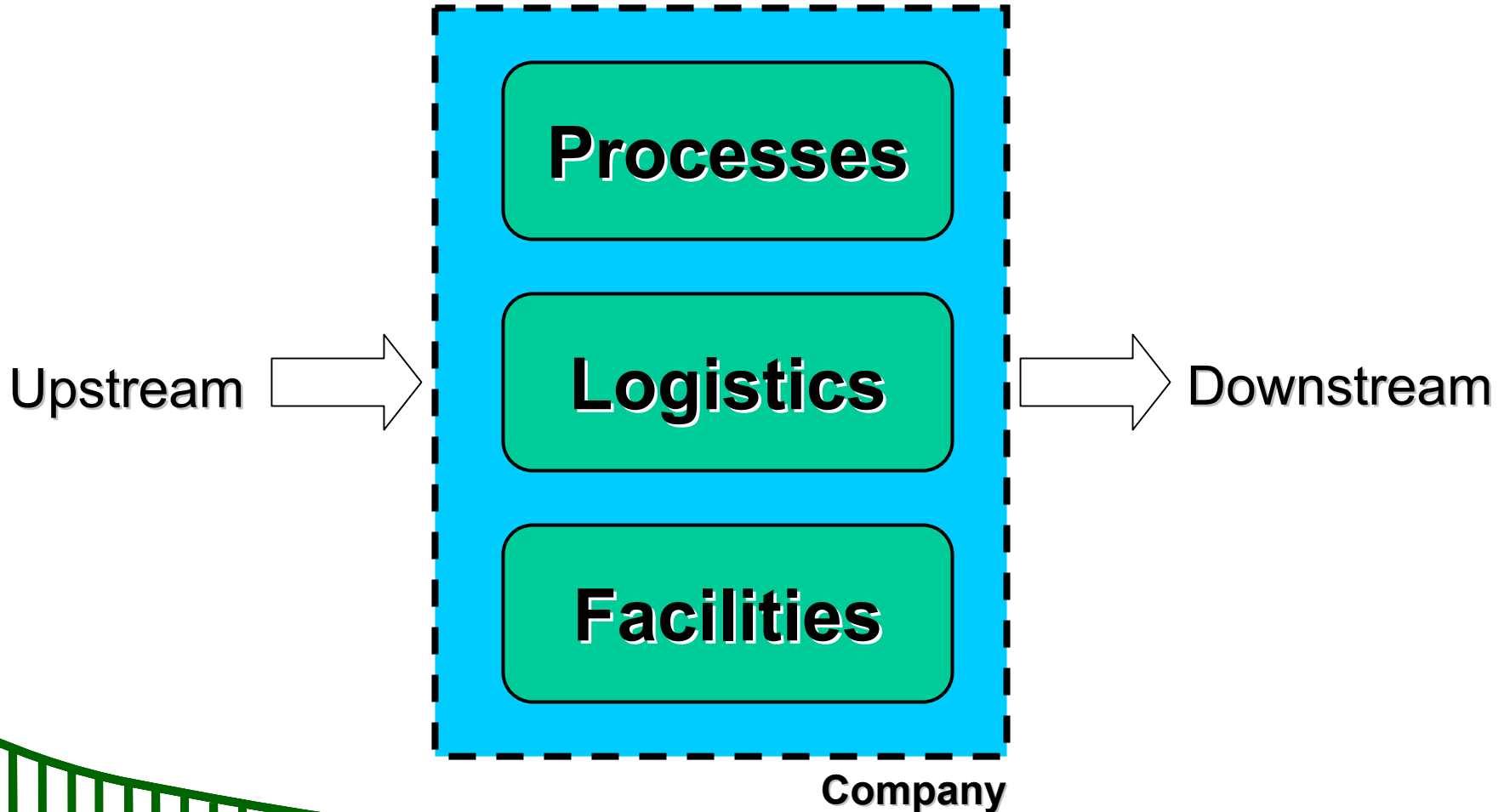
BRIDGESworks™ Metrics Software

- Screening tool
- Lay key issues on the table
- Extend boundaries on impact considerations
- Assist calculation and weighting of importance
- Facilitate benchmarking and standard setting
- Aim for management-friendly application

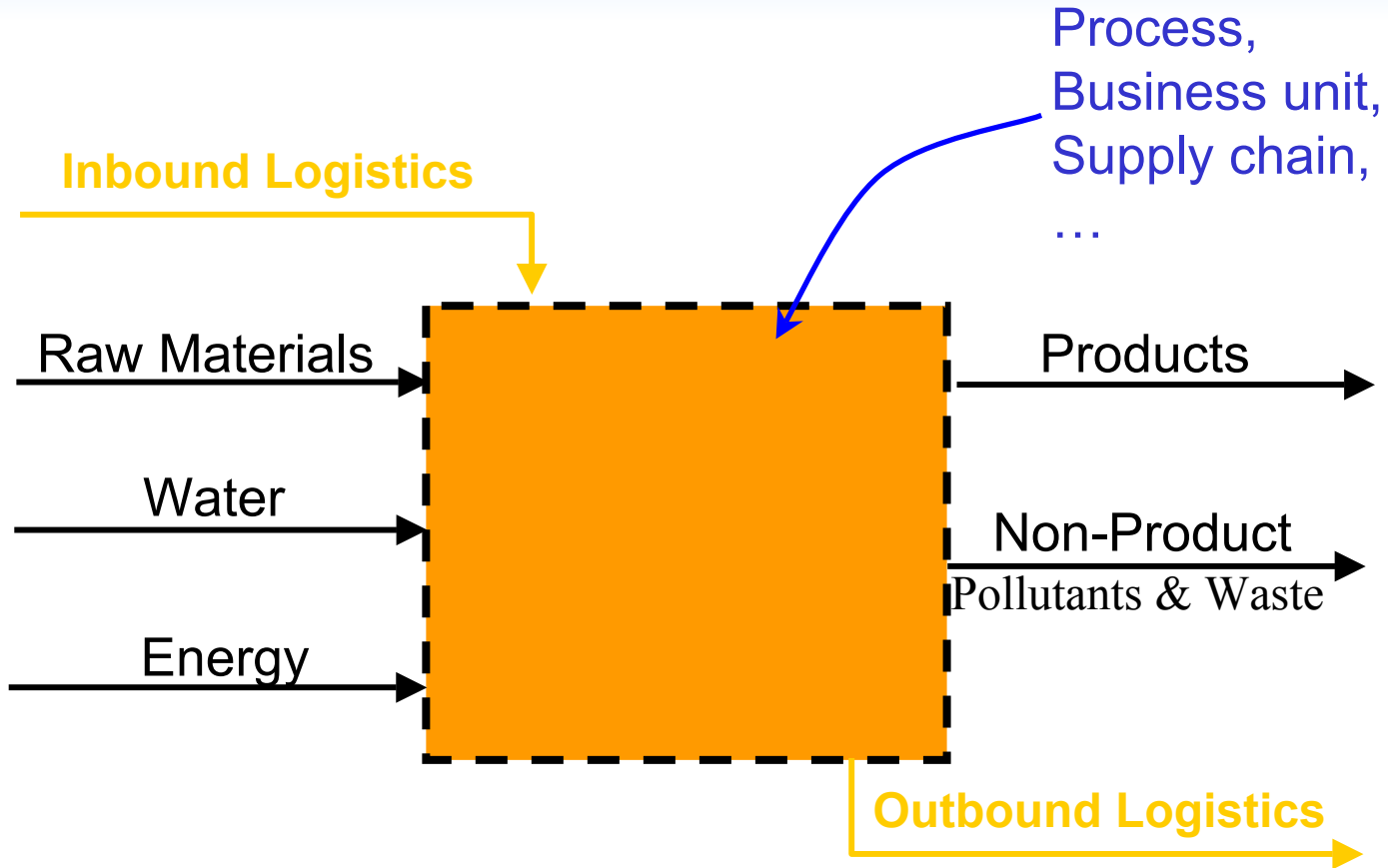
Metrics Criteria

- Simple
- Understandable
- Easy to reproduce / Comparable
- Complement regulatory programs
- Robust, non-perverse
- Cost-effective data collection
- Stackable and Scalable
- Useful management tools
- Protect company information

Metrics Scope



Metrics Scope



Basic Sustainability Metrics

Output:

Mass of product

Functional unit

Revenue

or

Value-Added

➤ **Material Intensity**

$$\frac{\text{Mass of Raw Materials} - \text{Mass of Products}}{\text{Output}}$$

➤ **Energy Intensity**

$$\frac{\text{Net Energy Consumed in Primary Fuel Equivalents}}{\text{Output}}$$

➤ **Water Consumption**

$$\frac{\text{Volume of Fresh Water Consumed}}{\text{Output}}$$

➤ **Toxic Release**

$$\frac{\text{Mass of Recognized Toxics}}{\text{Output}}$$

➤ **Pollutant Effects**

Complementary Metrics

- Material

- Packaging
- Percent renewable resources used
- Percent recycled materials used
- Toxics in product
- Toxics in raw materials
- Resource depletion (*with LCA*)

- Water

- Fate of rainwater
- Water consumption by source
- Water added to products
- Water use per availability

- Energy

- Feedstock energy consumed
- Percent renewable energy used

Complementary Metrics: Toxic & Pollutant Effects

- Human toxicity – carcinogenic
- Human toxicity – non-carcinogenic
- Ecosystem toxicity
- Global warming potential
- Photochemical ozone creation potential
- Air acidification potential
- Tropospheric ozone depletion potential
- Eutrophication potential

Weighted using available impact assessment methodologies
(e.g. TRACI)

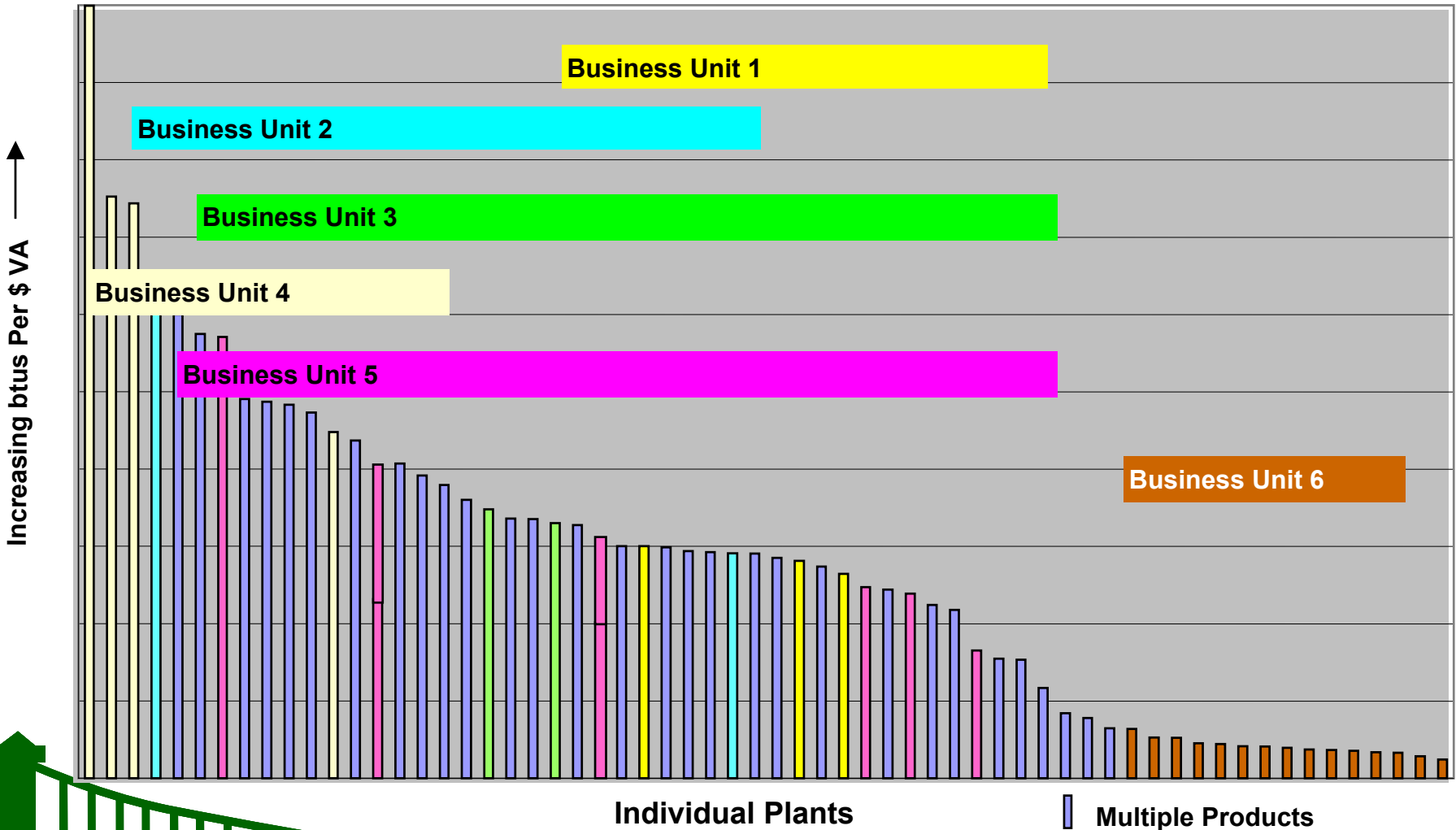
Comparing Metrics Across Product Slate

Product	Material			Energy			Water			Toxics			Pollutants			Greenhouse Gases		
	/lb	/\$Rev	/\$VA	/lb	/\$Rev	/\$VA	/lb	/\$Rev	/\$VA	/lb	/\$Rev	/\$VA	/lb	/\$Rev	/\$VA	/lb	/\$Rev	/\$VA
Polyethylene	0.021	0.061	0.145	1.185	3.386	8.124	0.447	1.277	3.064	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.283	0.809	1.942
Butadiene	0.018	0.146	0.729	1.059	8.763	43.623	0.359	2.971	14.791	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.139	1.151	5.732
Acetic Acid	0.062	0.283	0.395	1.823	8.287	11.592	1.239	5.632	7.878	0.00011	0.00049	0.00069	0.00000	0.00000	0.00000	0.133	0.607	0.849
PVC	0.049	0.084	0.145	3.634	6.266	10.827	0.619	1.067	1.843	0.00203	0.00351	0.00606	0.00000	0.00000	0.00000	0.410	0.708	1.223
Nylon 6	0.026	0.023	0.079	4.749	4.059	14.195	0.670	0.573	2.003	0.00469	0.00401	0.01403	0.00325	0.00278	0.00973	0.237	0.203	0.710
Formaldehyde	0.700	3.744	6.313	-0.427	-2.284	-3.852	1.397	7.475	12.602	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.296	1.585	2.672
Styrene	0.048	0.191	0.459	3.349	13.393	32.253	1.095	4.379	10.546	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.719	2.875	6.924
Aniline	0.432	1.094	6.426	-0.902	-2.286	-13.432	0.696	1.765	10.371	0.00002	0.00004	0.00023	0.00764	0.01937	0.11381	0.097	0.247	1.45
Chlorine	0.011	0.097	0.164	8.062	72.884	122.607	0.632	5.717	9.617	0.00000	0.00000	0.00000	0.00024	0.00215	0.00362	1.090	9.854	16.577
Maleic Anhydride	0.665	1.438	2.024	0.704	1.521	2.142	3.138	6.780	9.545	0.00163	0.00352	0.00495	0.00000	0.00000	0.00000	2.616	5.652	7.958
Hydrofluoric Acid	3.780	5.400	8.394	4.151	5.930	9.218	0.708	1.012	1.572	0.00680	0.00971	0.01510	0.04570	0.06528	0.10148	0.437	0.624	0.97
Ethylene	0.082	0.636	1.481	3.107	23.980	55.825	0.914	7.054	16.421	0.00058	0.00451	0.01050	0.00013	0.00104	0.00241	0.436	3.367	7.838
Ethylene Glycol	0.267	0.875	1.636	2.335	7.643	14.291	2.585	8.461	15.822	0.00756	0.02474	0.04626	0.00000	0.00000	0.00000	0.774	2.534	4.737
Phosphoric Acid	5.440	39.708	318.129	3.332	24.321	194.854	3.560	25.987	208.200	0.07202	0.52567	4.21150	0.00000	0.00000	0.00000	0.191	1.396	11.184
Acrylonitrile	0.493	1.475	4.678	5.211	15.598	49.456	3.372	10.096	32.009	0.01514	0.04533	0.14374	0.00781	0.02337	0.07410	0.966	2.891	9.167

Metrics developed from SRI Process Economics Program

Measuring Facility Performance

Primary Energy btus per \$ VA

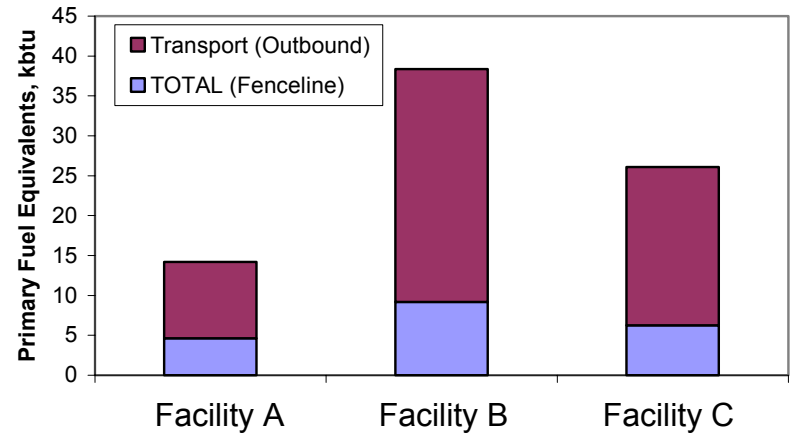
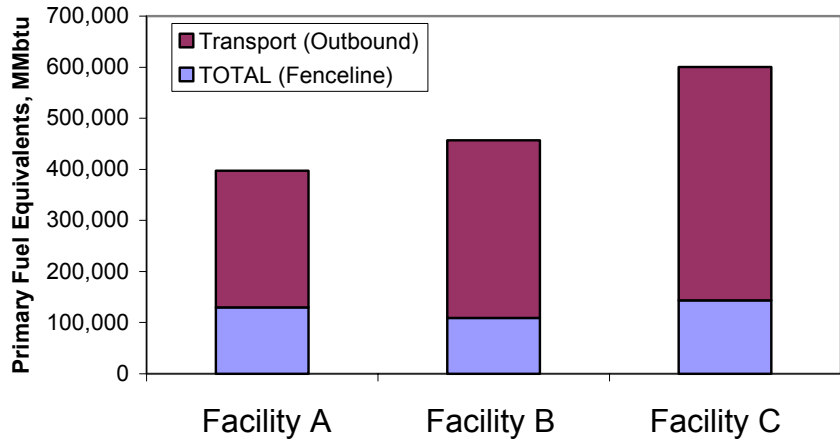




Extending Metrics – Transportation

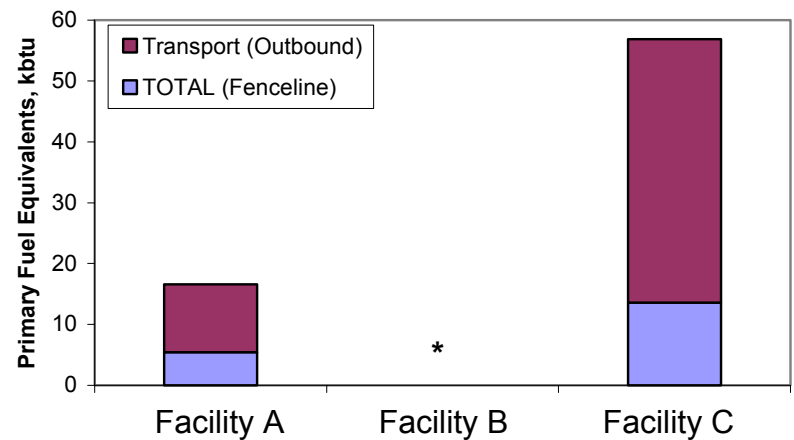
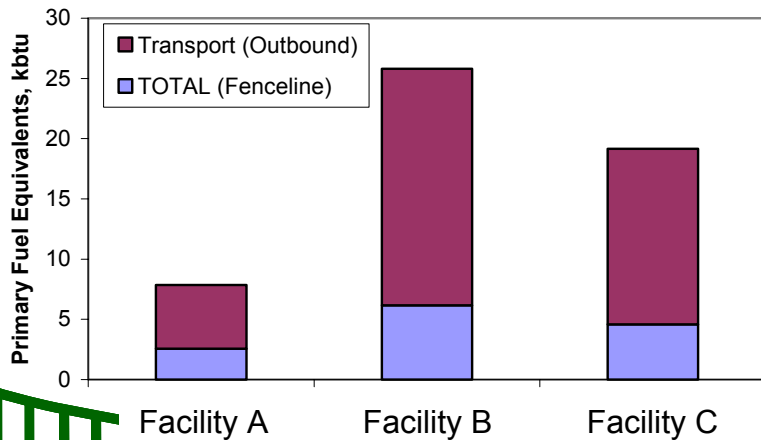
/year

/lb of product



/\$ Revenue

/\$ Value-Added



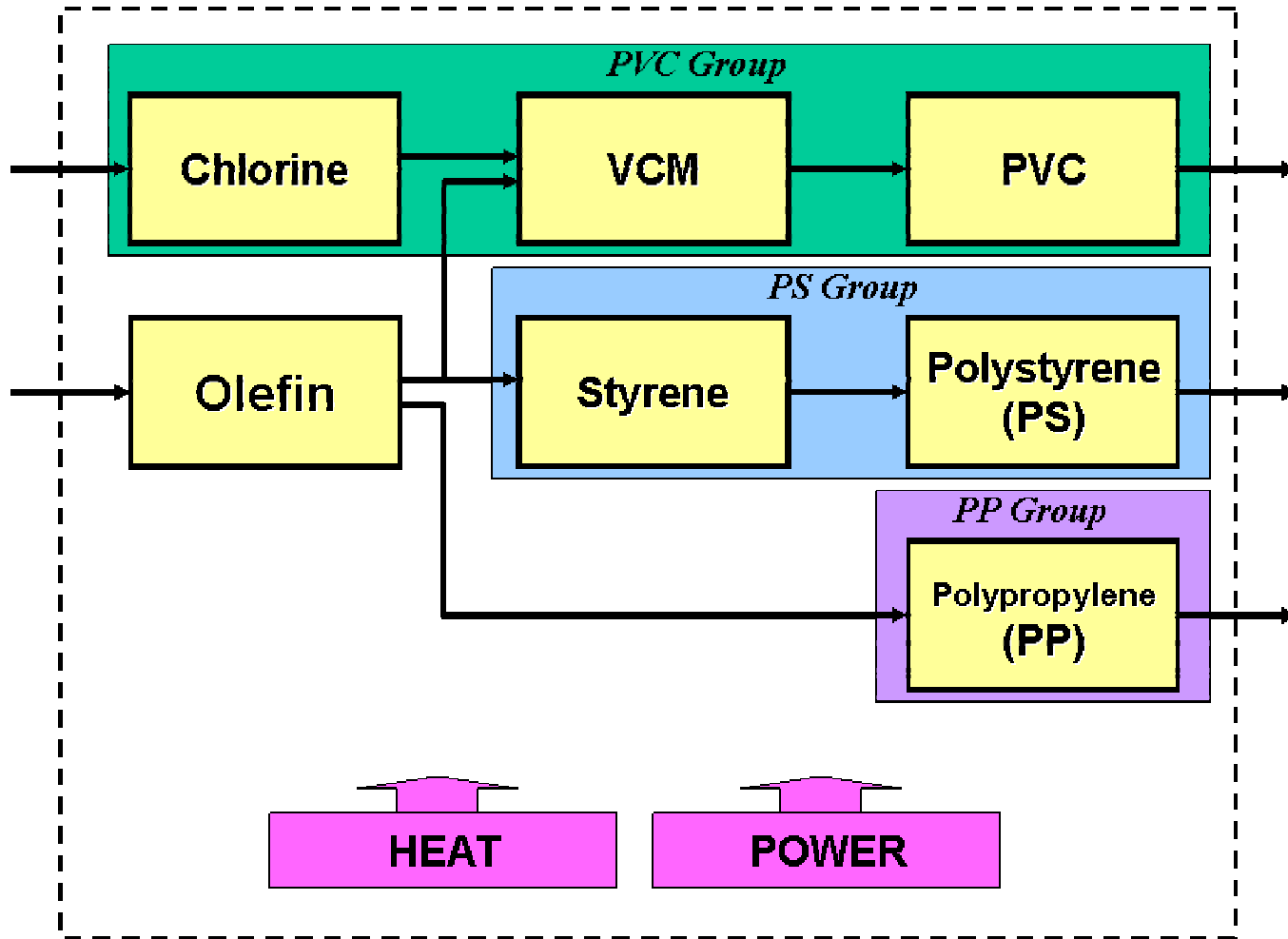
* Zero Value-Added

BRIDGESworks™ Metrics Software

- Metrics management tool
- Provides a metrics starting point
- Heuristics developed as default
- Incorporates benchmarks for 50+ chemicals
- Includes Impact Database
- Offers flexibility to build additional metrics
- Scalable, stackable
- Tracks performance
- Runs simulations
- Can be used in design
- Can produce benchmarks and signal thresholds
- Organizes data and results
- Retrieves legacy data through customization

Content unique to
BRIDGESworks™ Metrics

Example: 'ChemCo' Facility



Starting a Project

Project Properties

Project Name: ChemCo Facility

Created By: John Doe

Project Type: Business Unit Project

United States

Currency: \$ Input/Output

Project Description:

Last Modified By: John Doe

OK

Select metrics
Select units

Metrics Options

Material Metric Unit: lb

Calculate Recycled Raw Material metric

Calculate Toxic Raw Material metric

Energy Metric Unit: kbtu

Water Metric Unit: gal

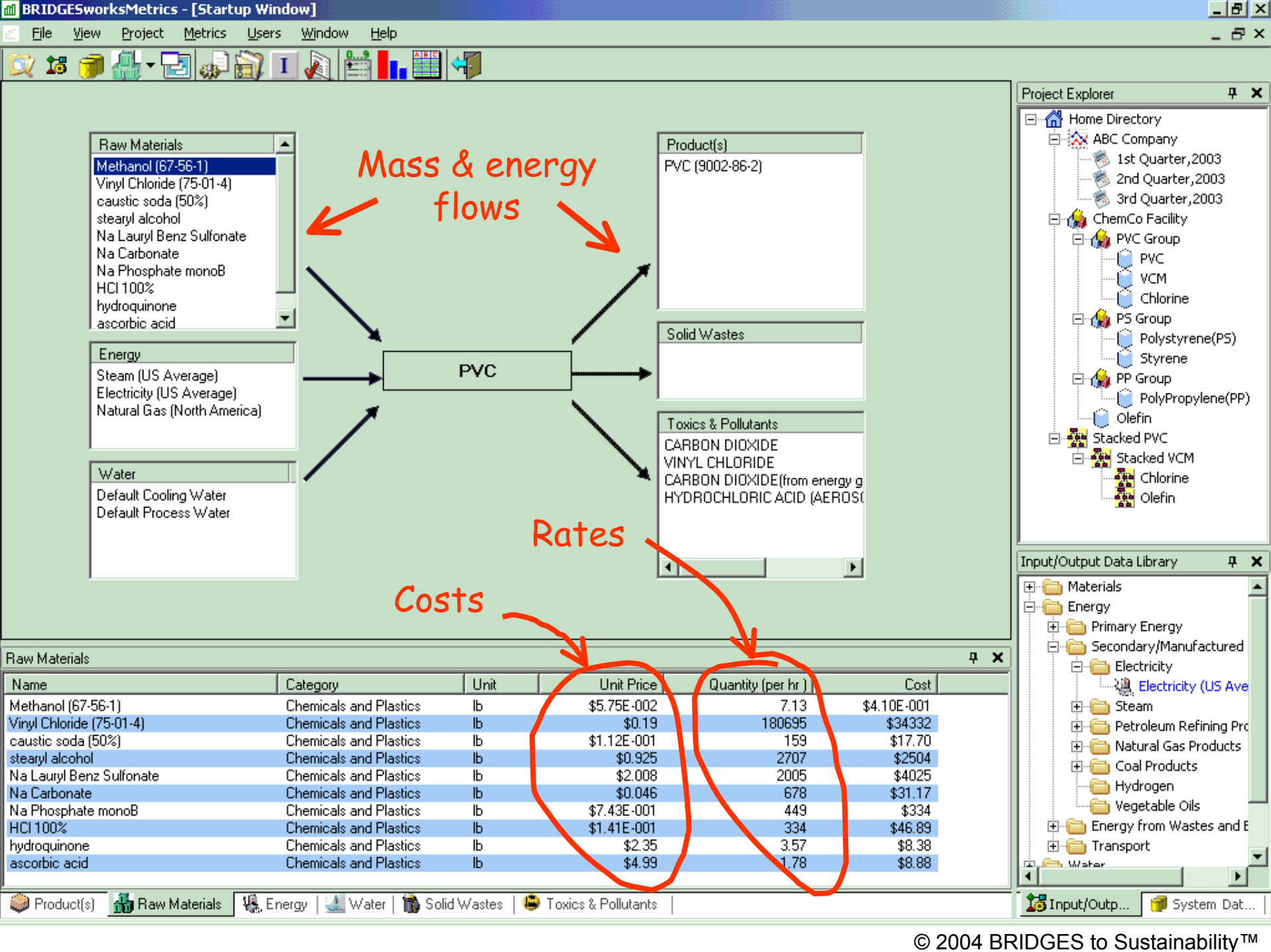
Data input by type of use (process, cooling or others)

Data input by source (municipal, ground, marine, etc.)

Calculate water usage affecting endangered ecosystem metric

Solid Waste Metric Unit: lb

OK Apply Cancel



Mass & energy flows

Rates

Costs

Raw Materials
Methanol (67-56-1)
Vinyl Chloride (75-01-4)
caustic soda (50%)
stearyl alcohol
Na Lauryl Benz Sulfonate
Na Carbonate
Na Phosphate monoB
HCl 100%
hydroquinone
ascorbic acid

Energy
Steam (US Average)
Electricity (US Average)
Natural Gas (North America)

Water
Default Cooling Water
Default Process Water

Product(s)
PVC (9002-86-2)

Solid Wastes

Toxics & Pollutants
CARBON DIOXIDE
VINYL CHLORIDE
CARBON DIOXIDE(from energy g
HYDROCHLORIC ACID (AEROS

Name	Category	Unit	Unit Price	Quantity (per hr)	Cost
Methanol (67-56-1)	Chemicals and Plastics	lb	\$5.75E-002	7.13	\$4.10E-001
Vinyl Chloride (75-01-4)	Chemicals and Plastics	lb	\$0.19	180695	\$34332
caustic soda (50%)	Chemicals and Plastics	lb	\$1.12E-001	159	\$17.70
stearyl alcohol	Chemicals and Plastics	lb	\$0.925	2707	\$2504
Na Lauryl Benz Sulfonate	Chemicals and Plastics	lb	\$2.008	2005	\$4025
Na Carbonate	Chemicals and Plastics	lb	\$0.046	678	\$31.17
Na Phosphate monoB	Chemicals and Plastics	lb	\$7.43E-001	449	\$334
HCl 100%	Chemicals and Plastics	lb	\$1.41E-001	334	\$46.89
hydroquinone	Chemicals and Plastics	lb	\$2.35	3.57	\$8.38
ascorbic acid	Chemicals and Plastics	lb	\$4.99	1.78	\$8.88

Project Explorer

- Home Directory
 - ABC Company
 - 1st Quarter, 2003
 - 2nd Quarter, 2003
 - 3rd Quarter, 2003
 - ChemCo Facility
 - PVC Group
 - PVC
 - VCM
 - Chlorine
 - PS Group
 - Polystyrene(PS)
 - Styrene
 - PP Group
 - PolyPropylene(PP)
 - Olefin
 - Stacked PVC
 - Stacked VCM
 - Chlorine
 - Olefin

Input/Output Data Library

- Materials
- Energy
 - Primary Energy
 - Secondary/Manufactured
 - Electricity
 - Electricity (US Ave
 - Steam
 - Petroleum Refining Pro
 - Natural Gas Products
 - Coal Products
 - Hydrogen
 - Vegetable Oils
 - Energy from Wastes and E
 - Transport
 - Water

Reviewing Assumptions

e.g.
electricity

Add/Edit Energy

Name: Electricity (US Average)

Energy Type: Electricity

Unit: kwh

Unit Price: \$ 0.036 /kwh

Description: Electricity generation, U.S. average 2002

Energy Generation/Trans Efficiency: 31 %

CO2 Conversion Factor: 1.829032258064 lb /kwh

Mix of Primary/Waste Energy Sources

Coal	51.8 %	Oil	2.9 %
Natural Gas	16.1 %	Nuclear	19.8 %
Renewables	9.4 %	Waste	0 %

Accept Cancel

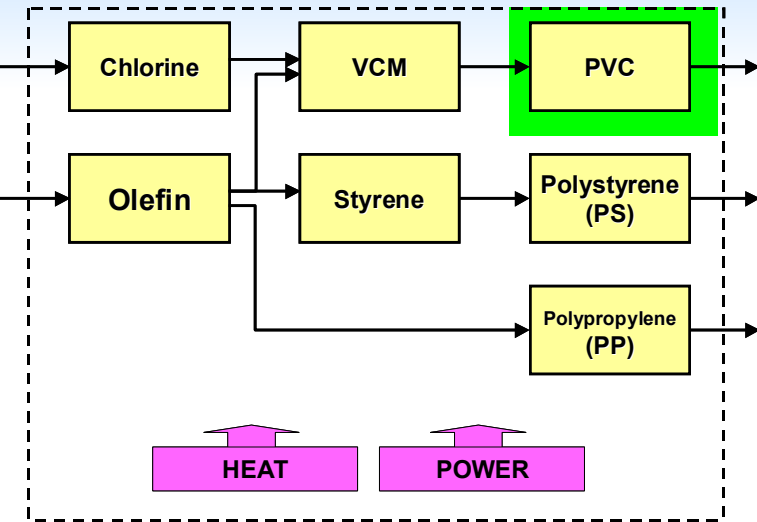
Efficiency

Fuel mix

Select Impact Assessments

Impact Assessment Options					
Category	Type	Method	Unit	Factor	Select
Toxicity	Ecosystem Toxicity	TRACI	lb	2,4-D equiv.	*
		CML-FAETP Inf. (Huijbregts, 1999&2000)	lb	1,4-Dichlorobenzene equiv.	
		EI-99 (H)		PDF*m2*yr	
		EI-99 (E)		PDF*m2*yr	
	Human Toxicity-Carcinogenic	TRACI	lb	C6H6 equiv	*
		EI-99 (H)		DALY	
		EI-99 (E)		DALY	
		EI-99 (I)		DALY	
	Human Toxicity-Non-Carcinogenic	CML-Human Toxicity Potential (HTP) Inf.	lb	1,4-Dichlorobenzene equiv.	
		TRACI	lb	C7H7 equiv.	*
Human Toxicity-Criteria	TRACI		DALY		
Pollutant	Atmospheric Acidification Potential	TRACI	mole	H+ equiv.	
		CML-AP (Hauschild & Wenzel (1998)	lb	SO2 equiv.	
	Global Warming Potential	TRACI	lb	CO2	*
		IPCC 2001(20-Year)	lb	CO2 equiv.	
		IPCC 2001(100-Year)	lb	CO2 equiv.	
		IPCC 2001(500-Year)	lb	CO2 equiv.	
	Eutrophication Potential	TRACI	lb	N	
		EP (Heijungs et al. 1992)	lb	PO4 equiv.	
	Ozone Depletion Potential	TRACI	lb	CFC-11	
		WMO 1992 ,1995 & 1999 (Steady State)	lb	CFC-11 equiv.	
Photochemical Ozone(Smog) Creation Potential	TRACI	lb	NOX equiv.		
	CML-POCP (Jenkins et al. 1999)	lb	Ethylene equiv.		
General	General Impact	EPS (Steen,1999)		elu	

Metrics – Successively Larger Scale



PVC Process

BRIDGEworksMetrics - [Metrics Report]

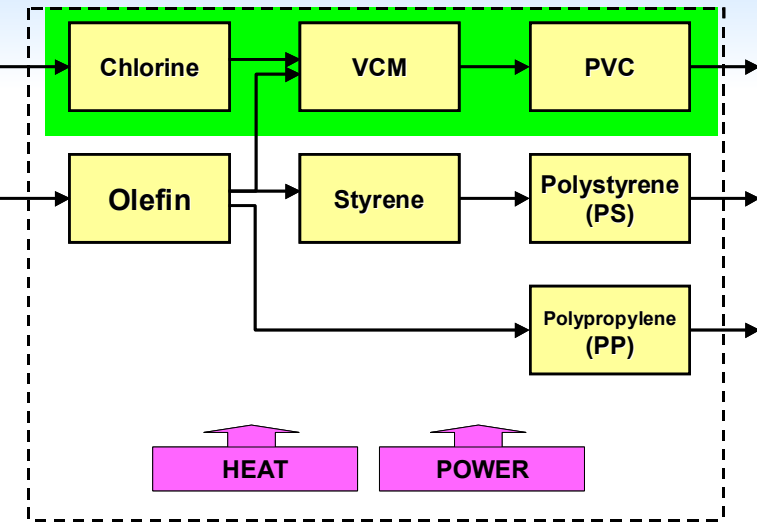
MainReport

PVC

Metric	Unit	/lb Product(s)	/\$ Revenue	/\$ VA
Material	lb	0.049	0.084	0.145
Energy	kbtu	3.94	6.79	11.72
Water	gal	0.619	1.07	1.84
Solid Waste	lb			
Toxic & Pollutant Impact				
--Ecosystem Toxicity--TRACI	lb 2,4-D equiv.	1.86E-011	3.21E-011	5.55E-011
--Global Warming Potential--IPCC 2001(100-Year)	lb CO2 equiv.	0.709	1.22	2.11
--General Impact--EPS (Steen,1999)	elu	0.077	0.132	0.228

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Metrics – Successively Larger Scale



PVC "Group"

BRIDGEsworksMetrics - [Metrics Report]

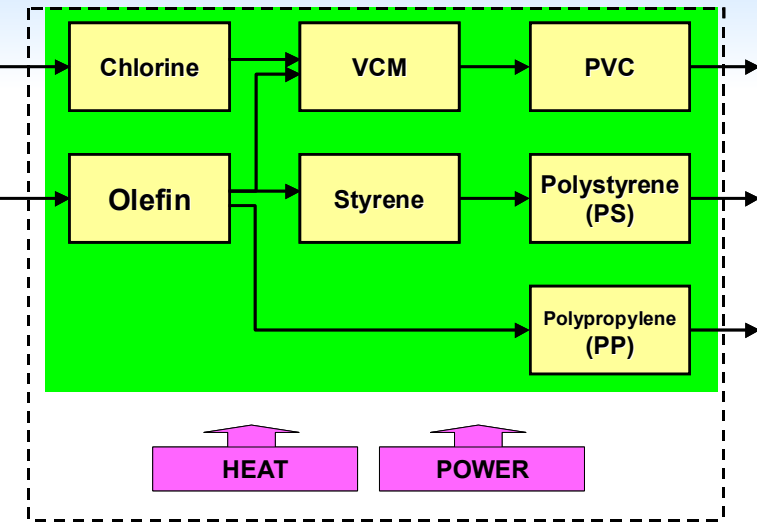
MainReport

PVC Group

Metric	Unit	/lb Product(s)	/\$ Revenue	/\$ VA
Material	lb	0.124	0.392	0.538
Energy	kbtu	10.97	34.60	47.52
Water	gal	1.77	5.58	7.66
Solid Waste	lb			
Toxic & Pollutant Impact				
--Global Warming Potential--TRACI	lb CO2	1.97	6.22	8.54
--Ecosystem Toxicity--TRACI	lb 2,4-D equiv.	9.11E-011	2.87E-010	3.95E-010
--Human Toxicity-Carcinogenic--TRACI	lb C6H6 equiv	7.01E-005	2.21E-004	3.04E-004

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Metrics – Successively Larger Scale



Facility

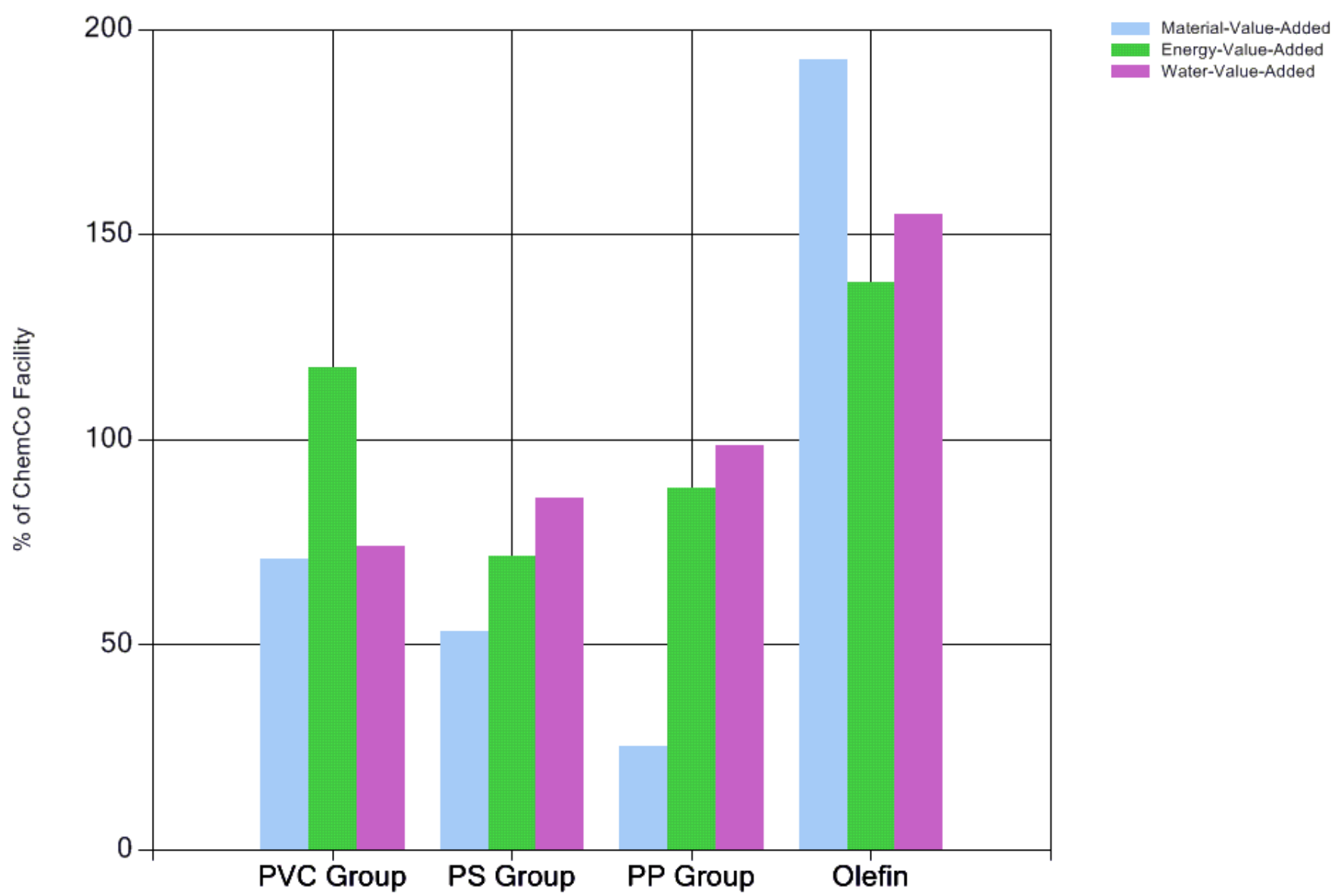
BRIDGESworksMetrics - [Metrics Report]

MainReport

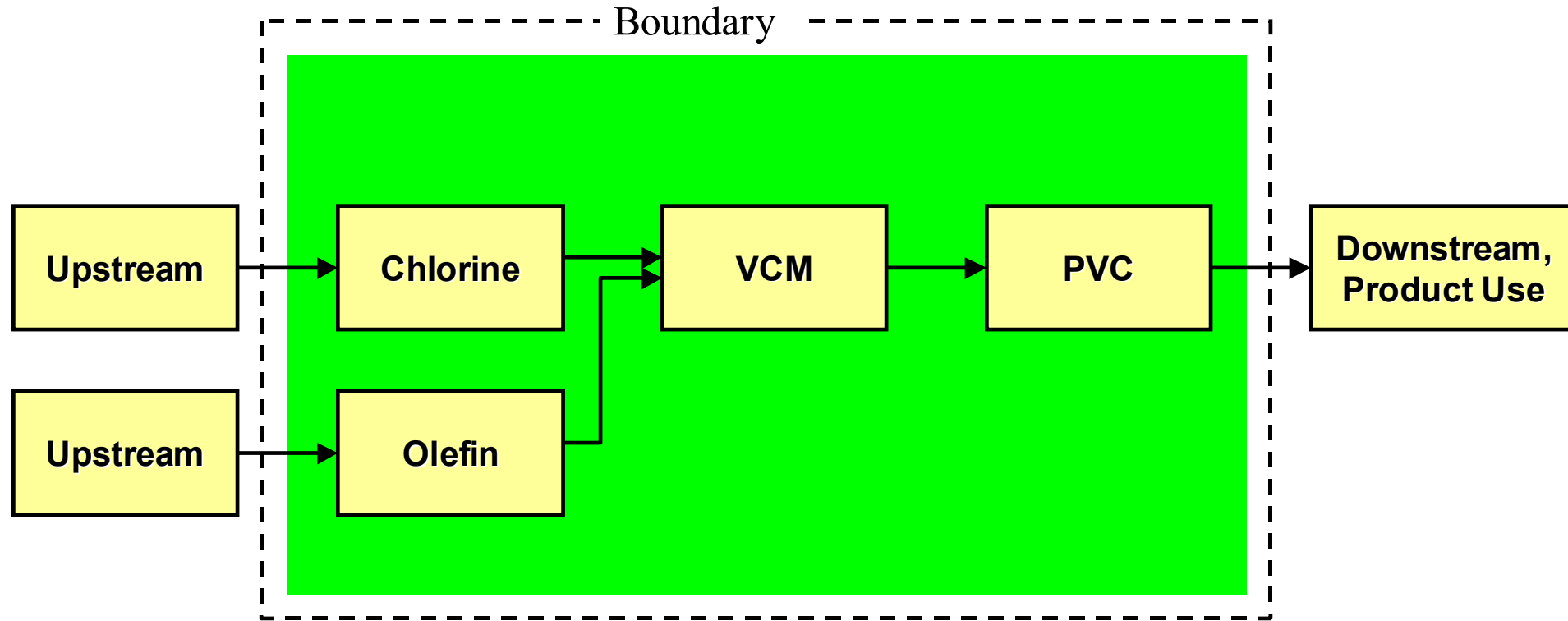
ChemCo Facility

Metric	Unit	/lb Product(s)	/\$ Revenue	/\$ VA
Material	lb	0.124	0.522	0.758
Energy	kbtu	6.61	27.82	40.42
Water	gal	1.69	7.13	10.35
Solid Waste	lb			
Toxic & Pollutant Impact				
--Global Warming Potential--TRACI	lb CO2	1.49	6.29	9.13
--Ecosystem Toxicity--TRACI	lb 2,4-D equiv.	1.05E-008	4.42E-008	6.42E-008
--Human Toxicity-Non-Carcinogenic--TRACI	lb C7H7 equiv.	2.18E-003	9.16E-003	0.013
--Human Toxicity-Carcinogenic--TRACI	lb C6H6 equiv.	4.11E-005	1.73E-004	2.52E-004

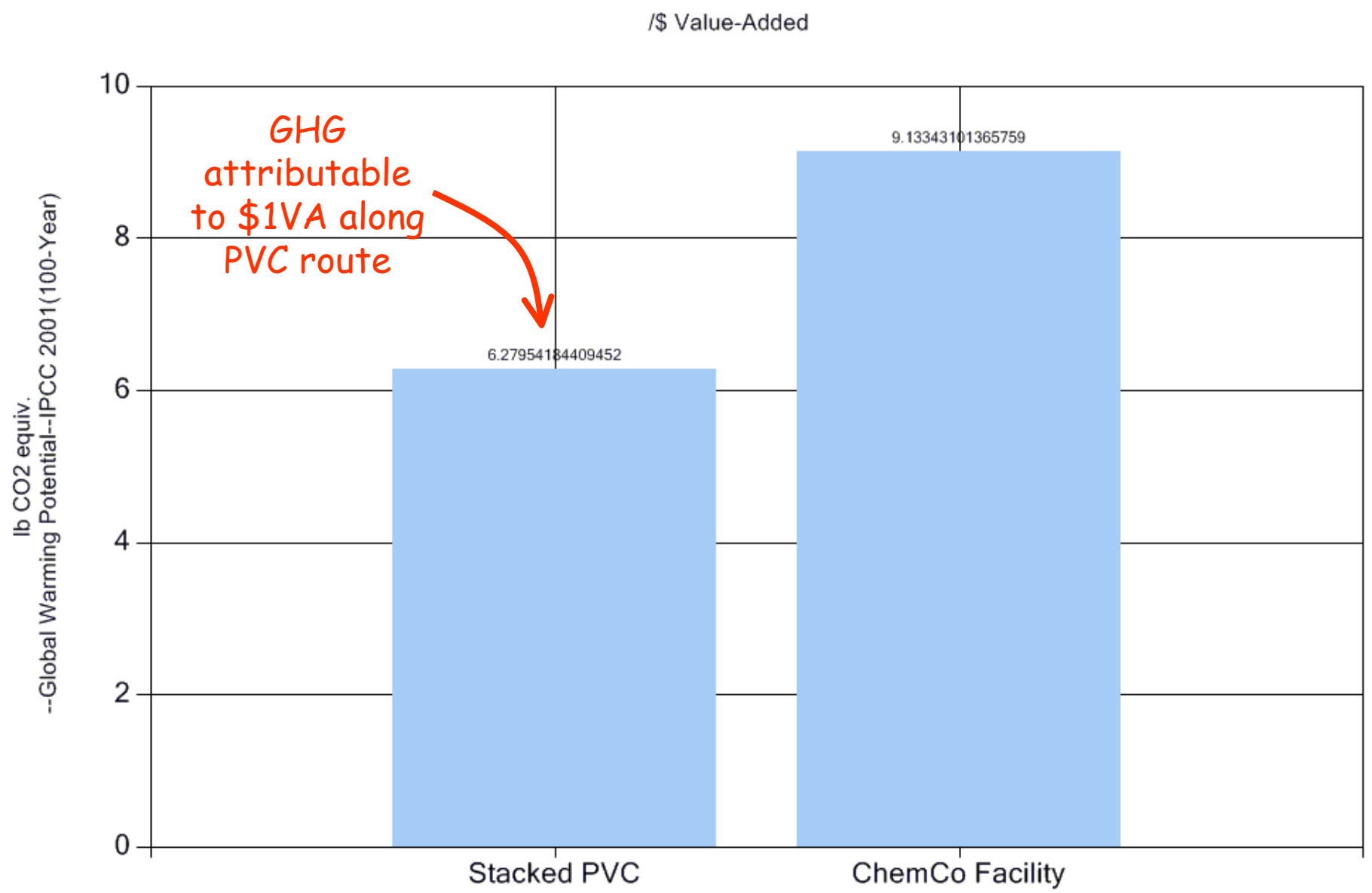
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“Stacking”

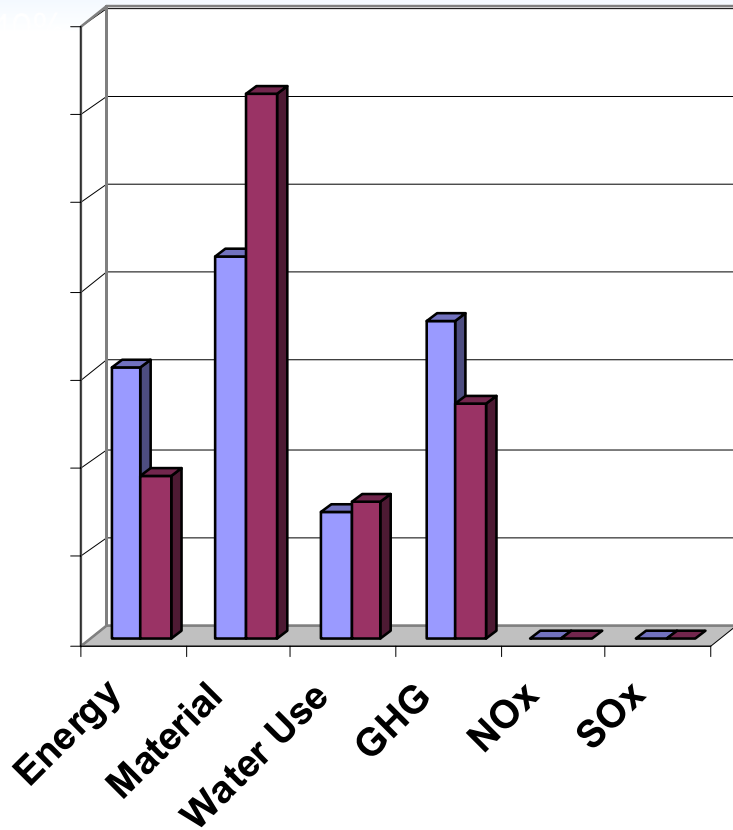


Aggregating impacts attributable to 1 unit of output (e.g. 1 lb of PVC) from within the boundary

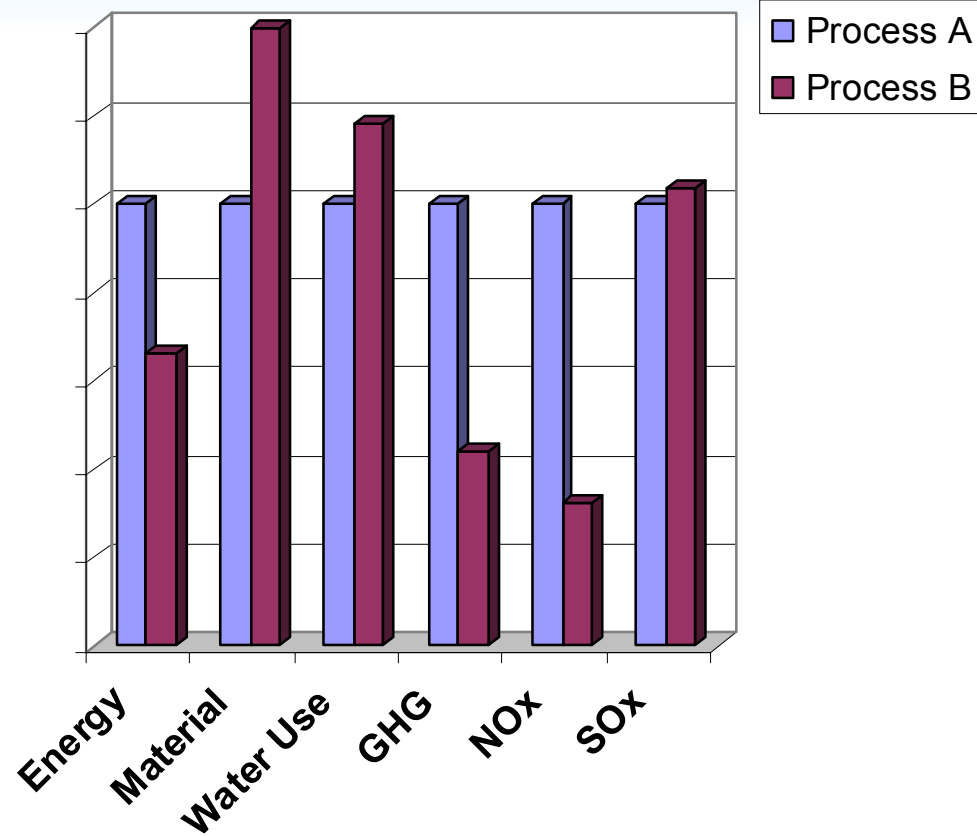


Linking Metrics to LCA

Maleic Anhydride Production



Manufacture Stage



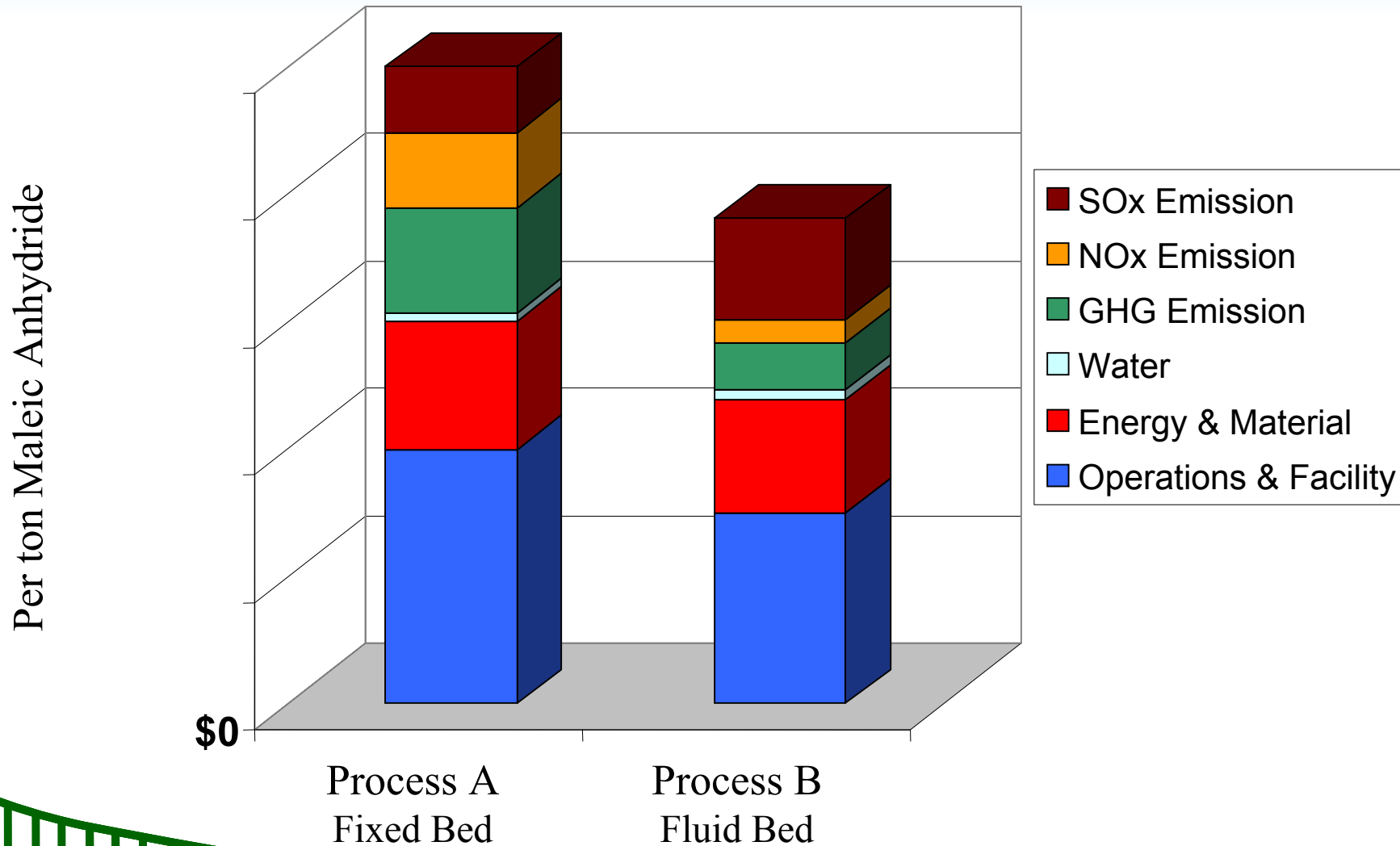
“Cradle-to-Gate”

Metrics expressed as % of “cradle-to-gate”

Process A: via fixed-bed reactor;
Process B: via fluidized-bed reactor

Linking Metrics to TCA

Maleic Anhydride Production



Future Development

- Normalization and weighting → single “environmental impact” score
- Object-oriented GUI for ease of use by management
- Integrating BRIDGESworks™ Metrics with LCA and TCA software (SimaPro and TCace)
- Developing benchmarks for all SIC codes
- Expansion of metrics to land use and social



*Thank
You!*

For more info:

www.bridgestos.org