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

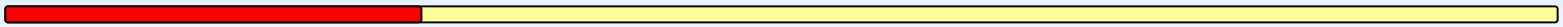
Implementing Sustainability

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

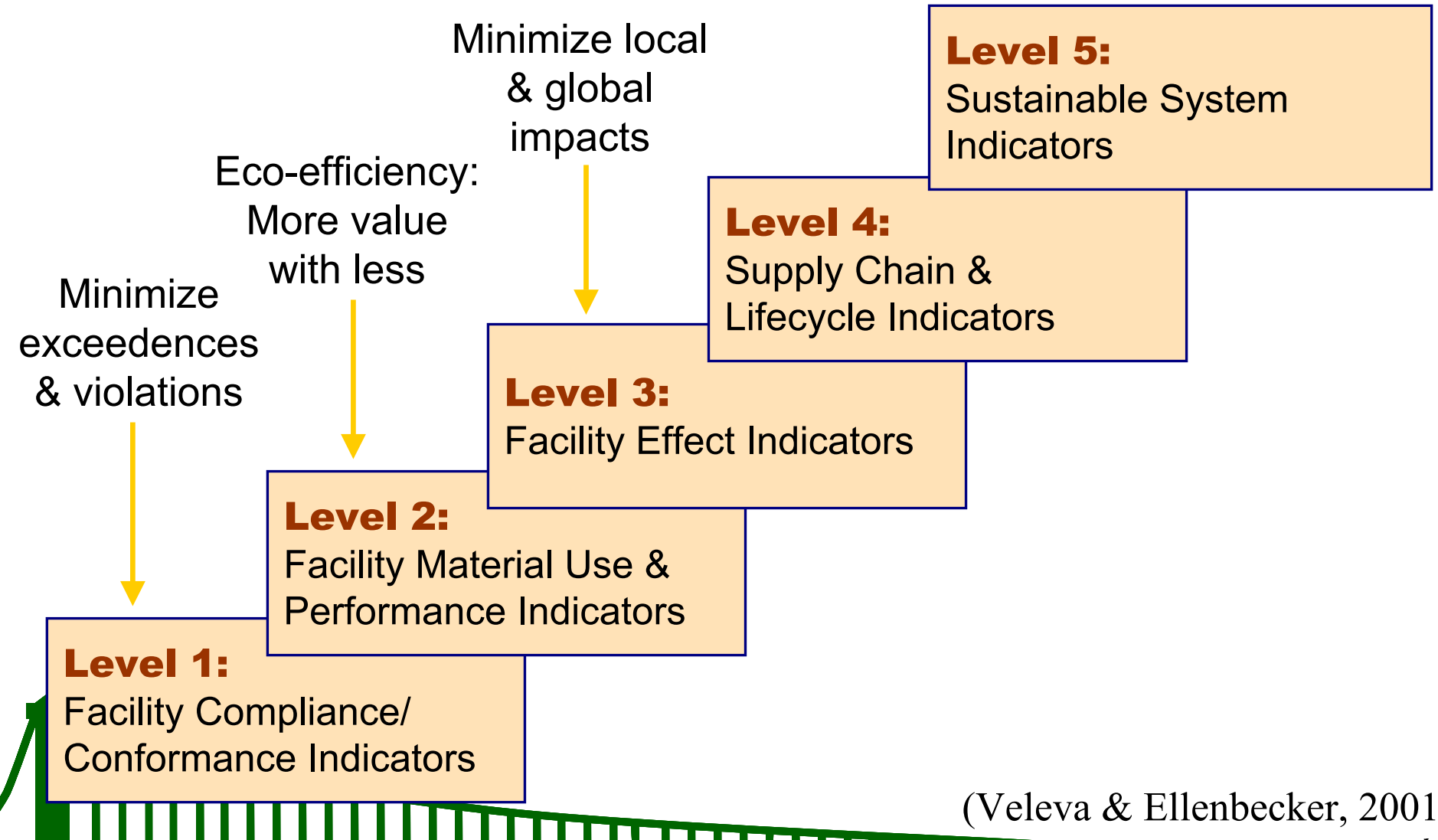
2001	DOE / AIChE / SRI	Developed metrics for 50+ chemical processes using PEP data
2001	DOE / AIChE	"Practical Minimum Energy" as baseline for energy metrics
2002	EPA / GCHSRC	Linked Sustainability Metrics with Total Cost Assessment
2002	BRIDGES	Initiated development of BRIDGESworks™ Metrics software

Metrics Development at BRIDGES

1999 2000 2001 2002 present

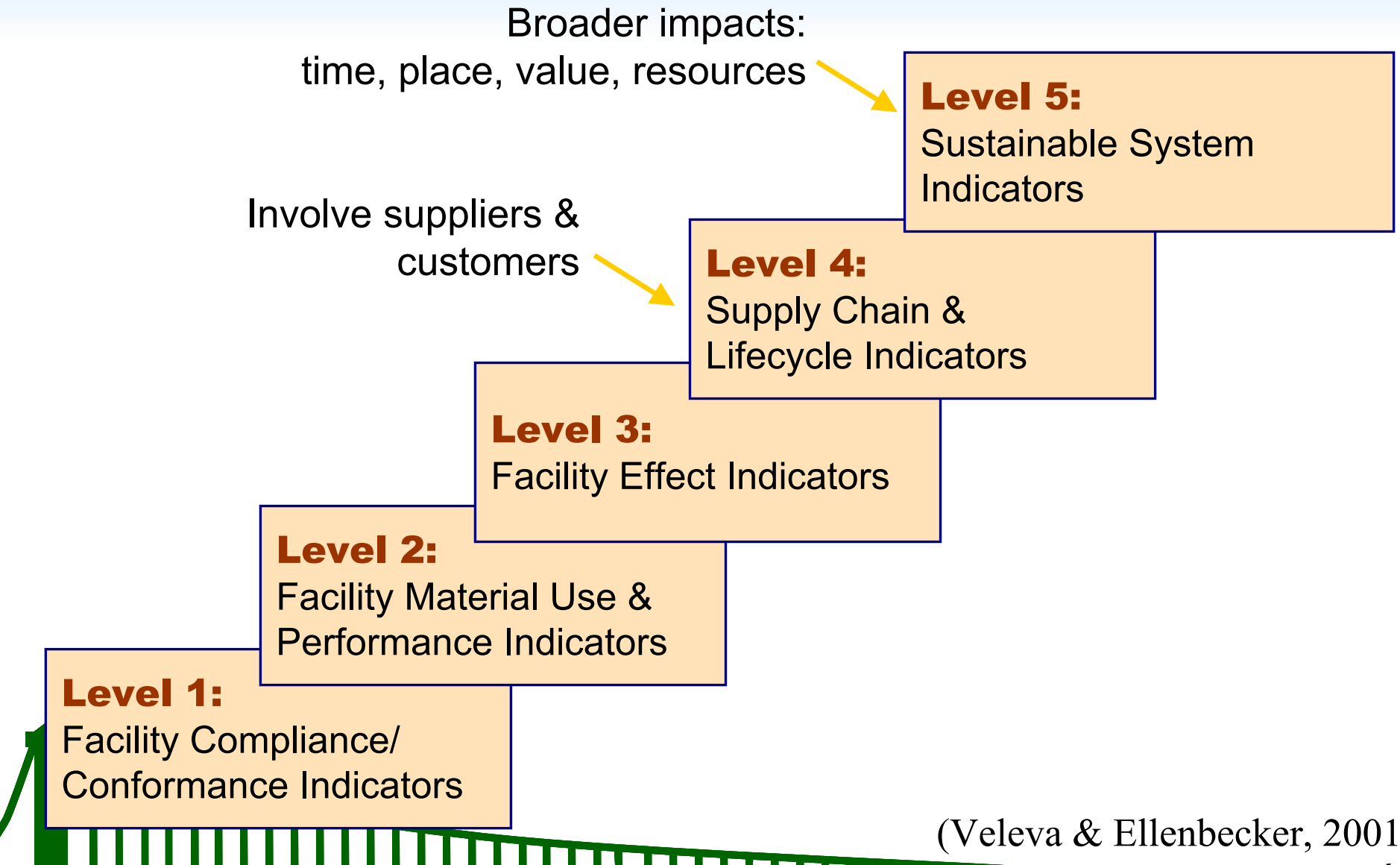
2003	The Stanley Works	Pilot metrics for Board Meeting (with *covergence consulting*)
2003	NSF / Caterpillar	Pilot metrics for product design
2004	The Stanley Works	Expansion of metrics project to Asia, upstream and downstream
2004	AIChE / IfS	Partnership intent: develop educational software, case studies, industry pilots, markets

Evolution of Environmental Metrics



(Veleva & Ellenbecker, 2001)

Evolution of Environmental Metrics



(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 mat
  - Iden
  - Eva
  - Evaluate R&D alternatives / innovations
- Track performance
- External reporting

Produce ***insights*** to broad range of players

Produce *insights* to broad range of players

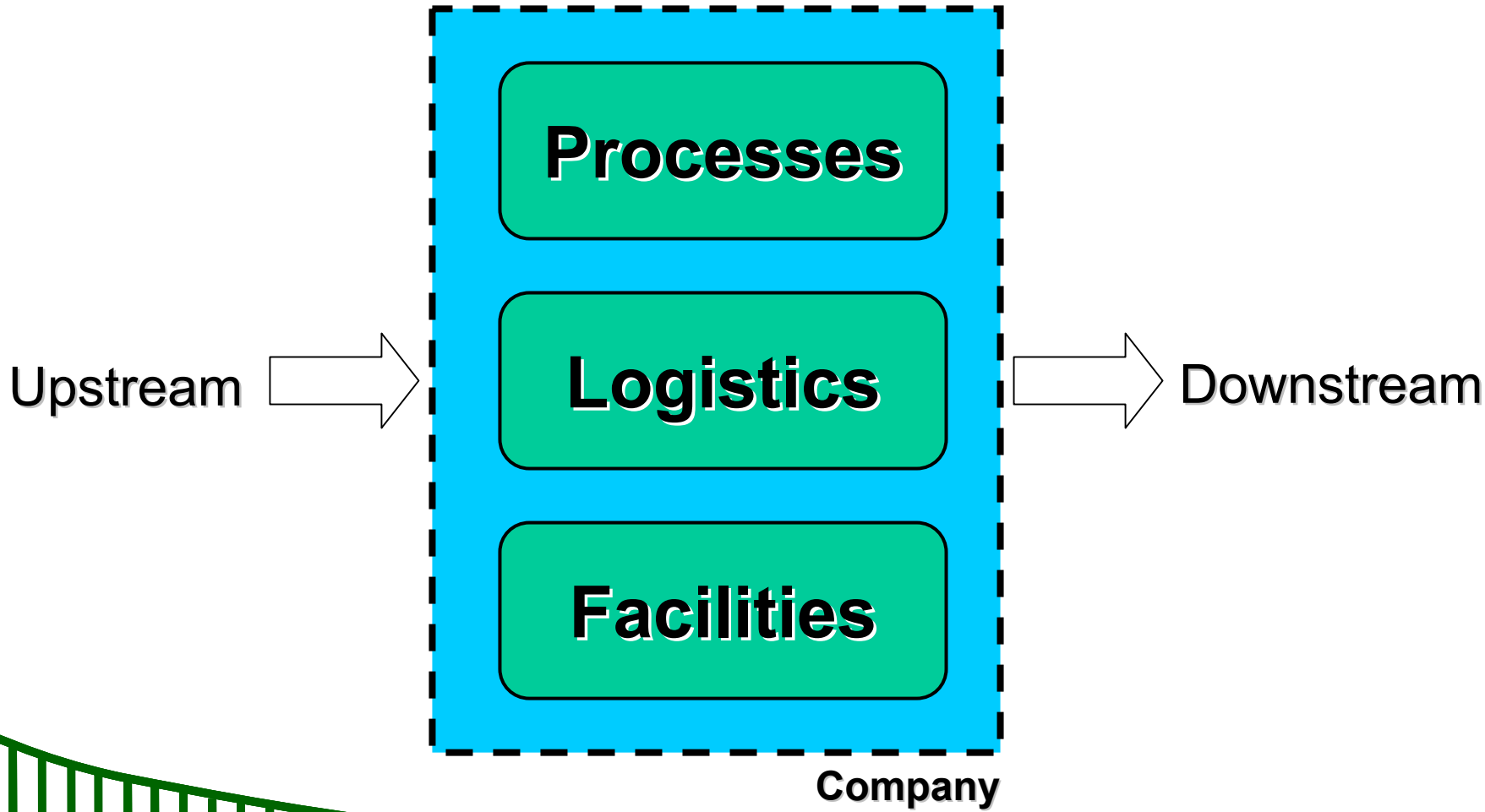
BRIDGESworks™ Metrics Software

- 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

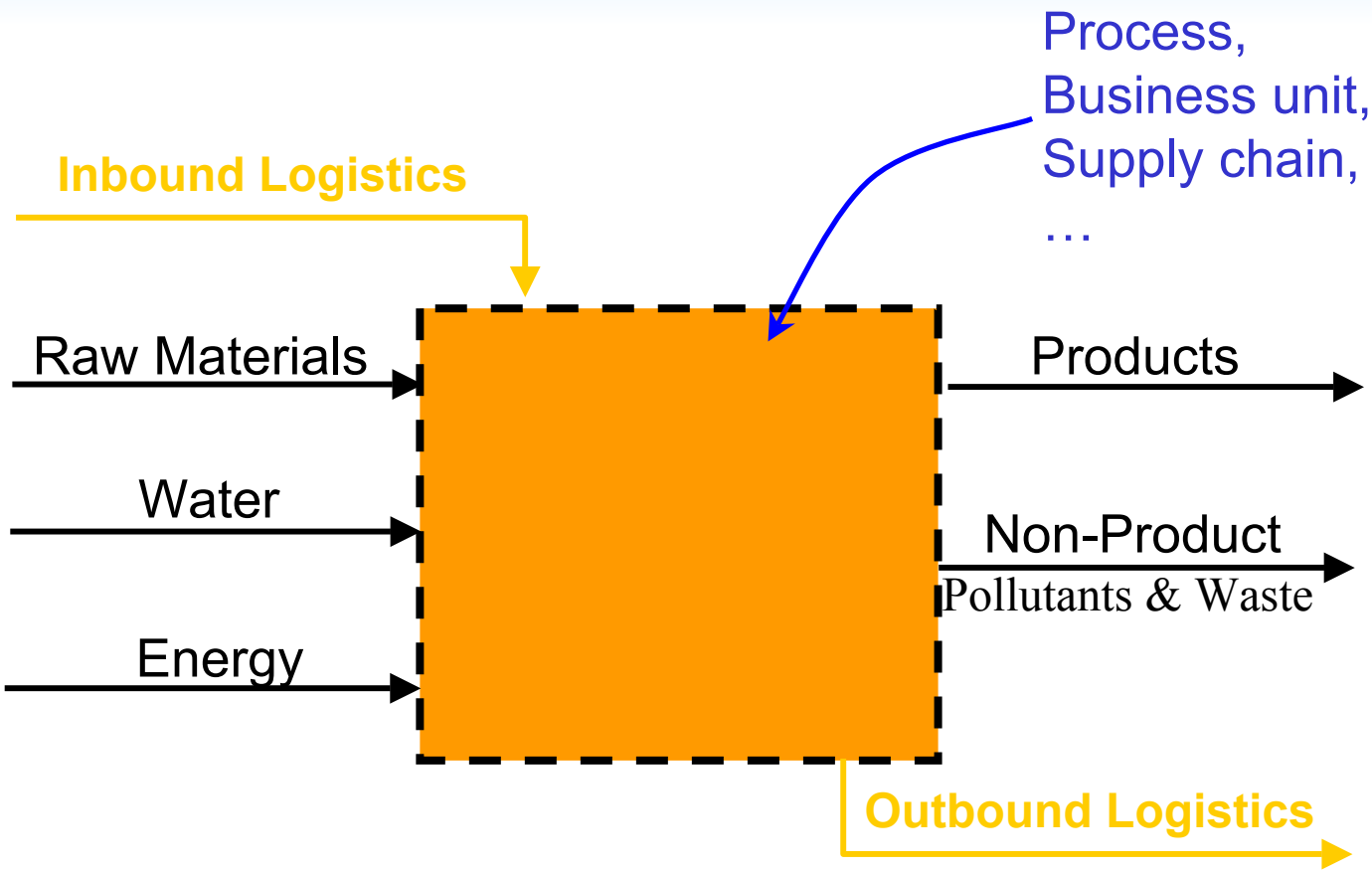
Metrics Criteria

- 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**

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

- **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

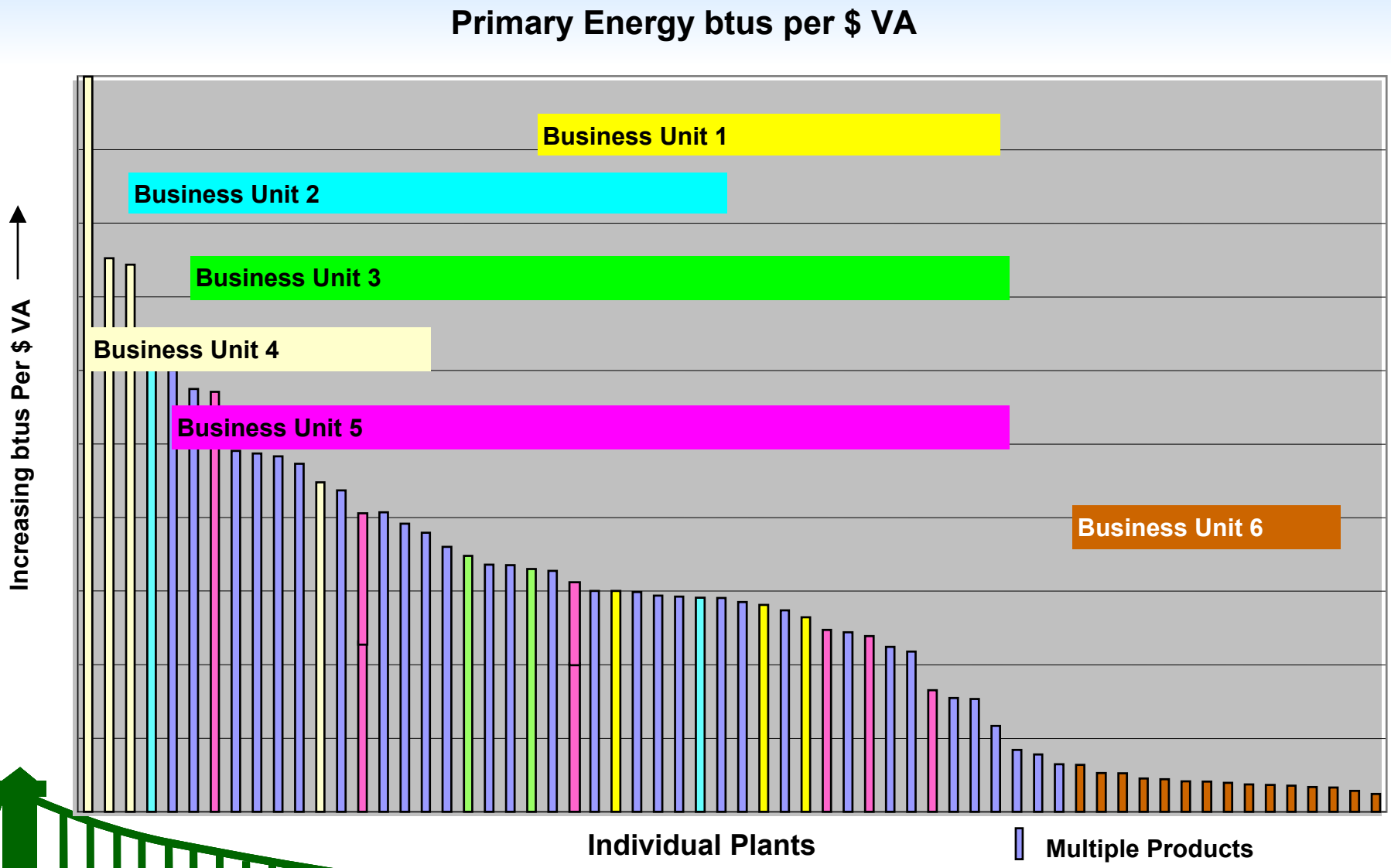
Weighted using available impact assessment methodologies (e.g. TRACI)

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

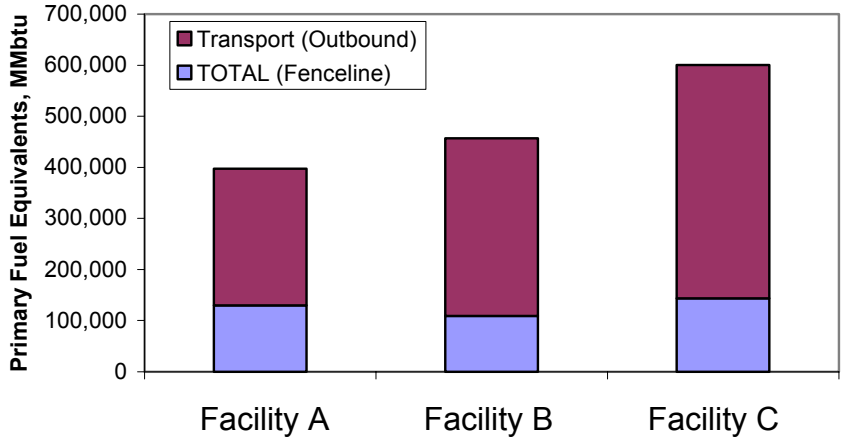
Metrics developed from SRI Process Economics Program

Measuring Facility Performance

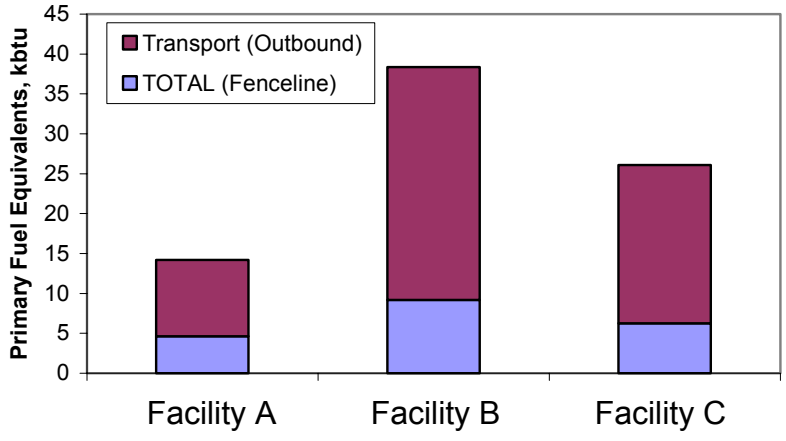


Extending Metrics – Transportation

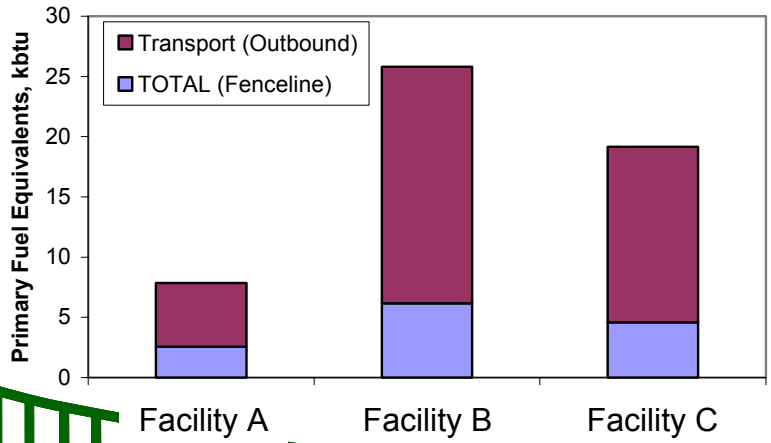
/year



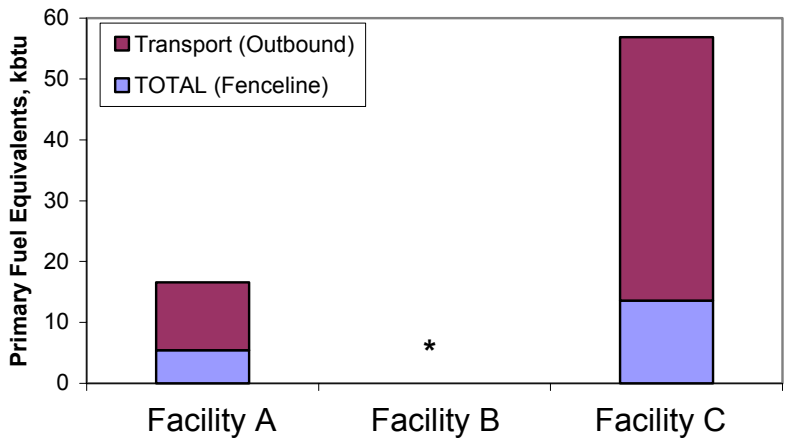
/lb of product



/$ Revenue



/$ Value-Added



* Zero Value-Added

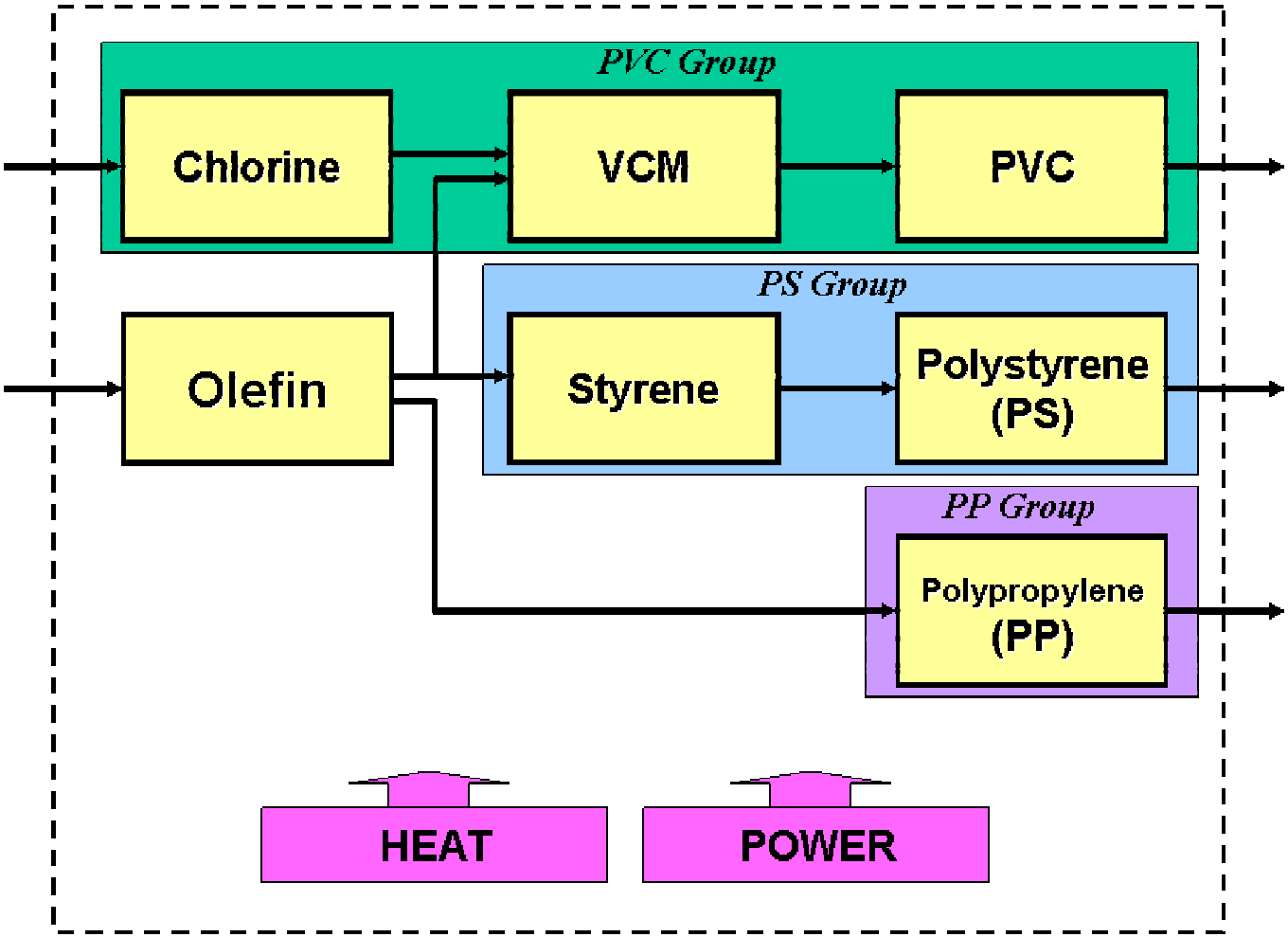
BRIDGESworks™ Metrics Software

- 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

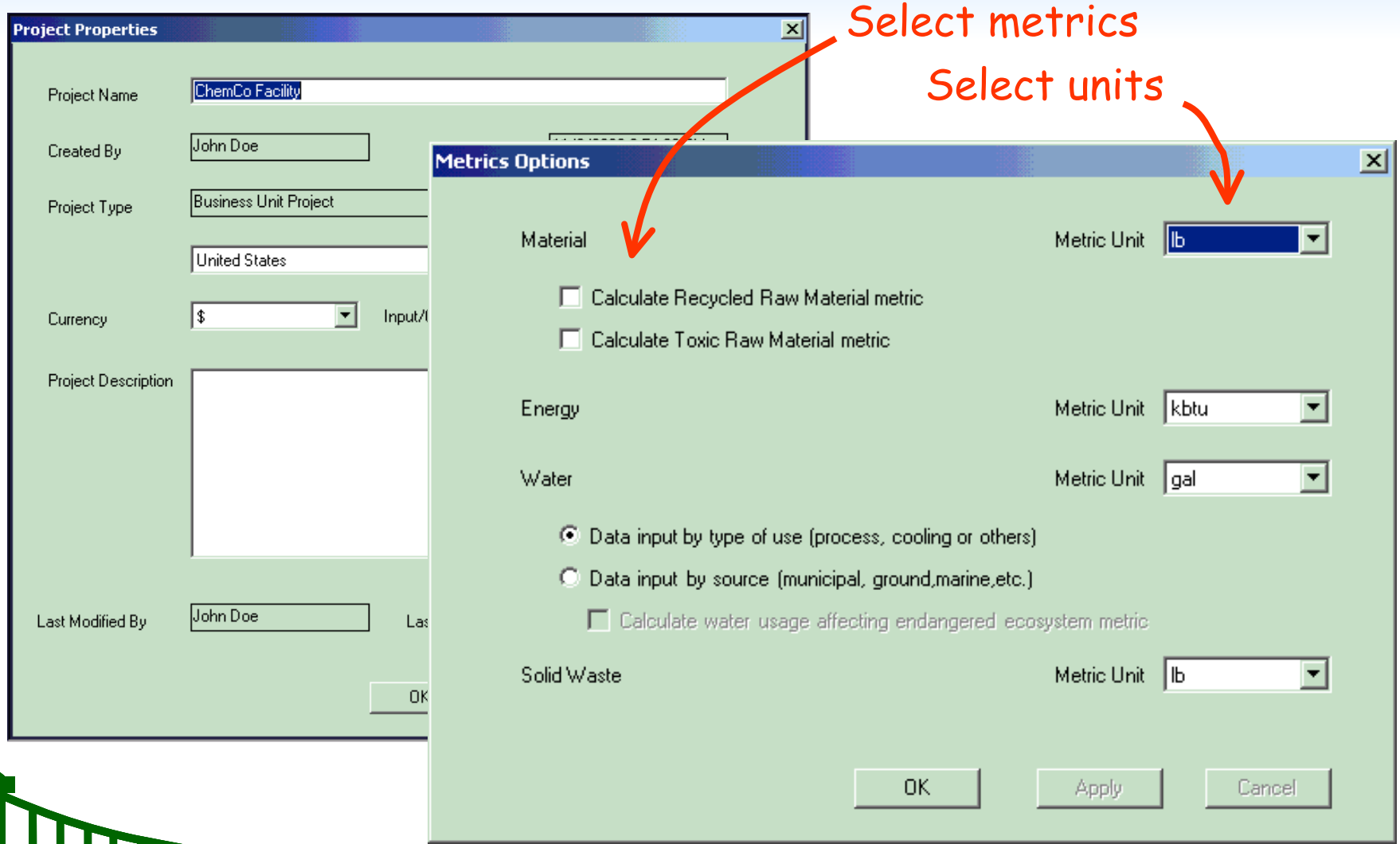
- Scalable, stackable
- Tracks performance
- Runs simulations
- Can be used in design
- Can produce benchmarks and signal thresholds
- Organizes data and results
- Retrieves legacy data through customization

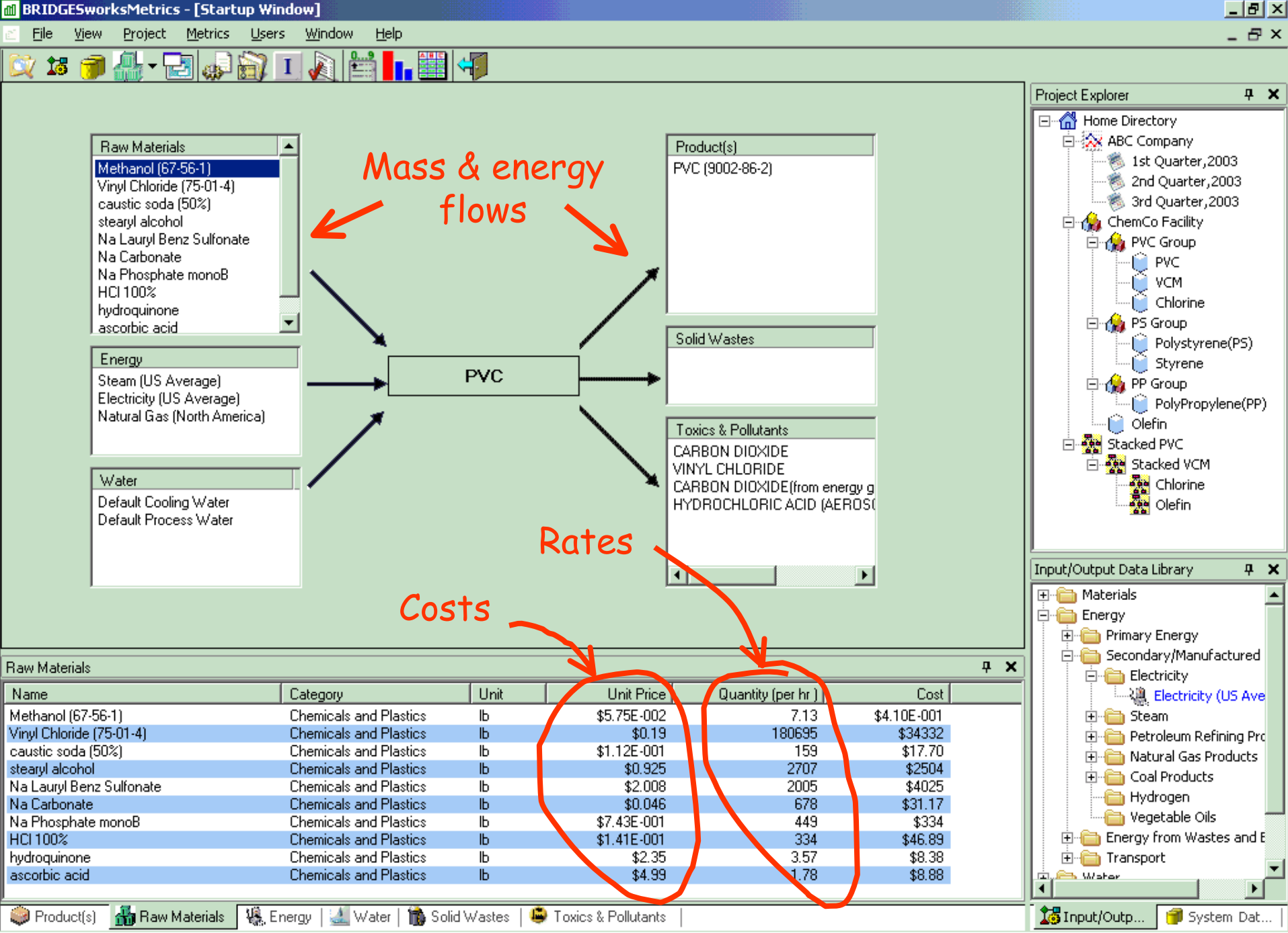
Content unique to BRIDGESworks™ Metrics

Example: 'ChemCo' Facility

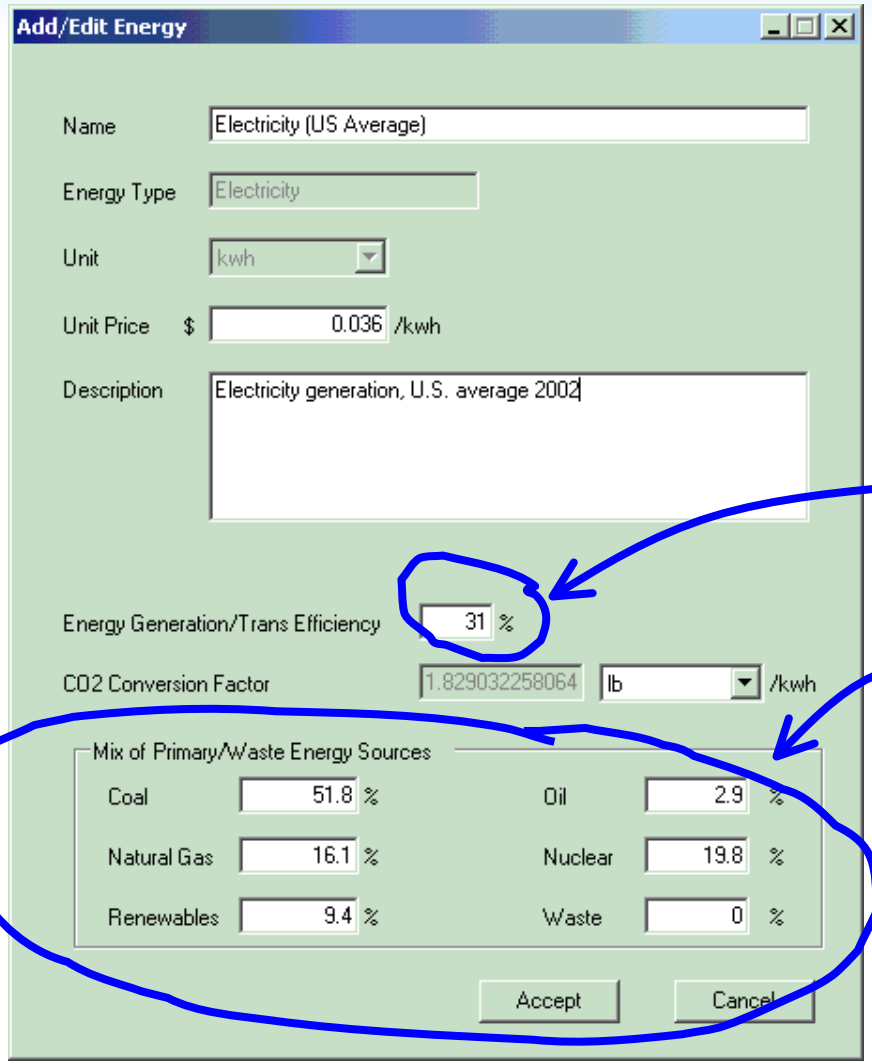


Starting a Project





Reviewing Assumptions

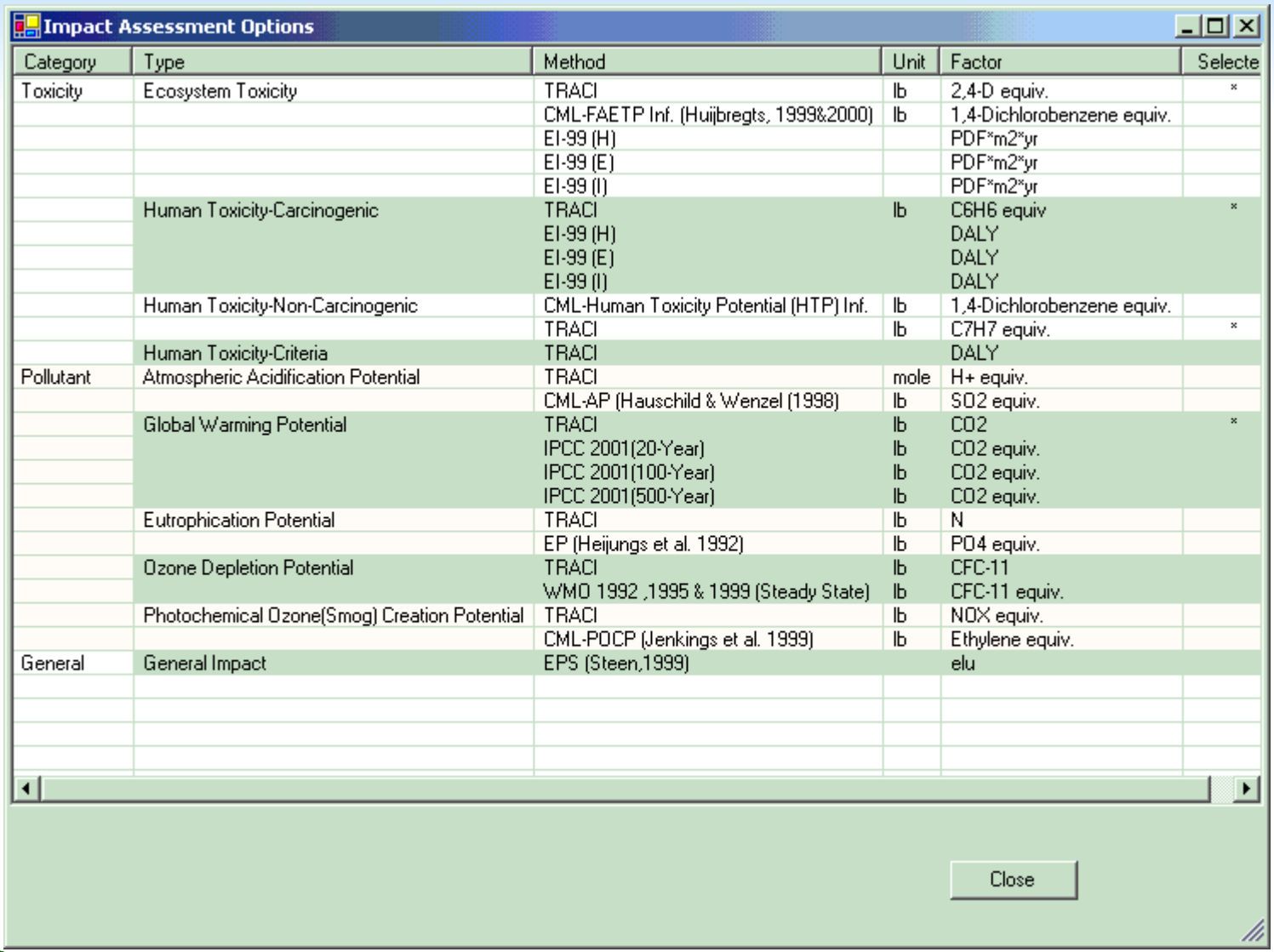


e.g. electricity

Efficiency

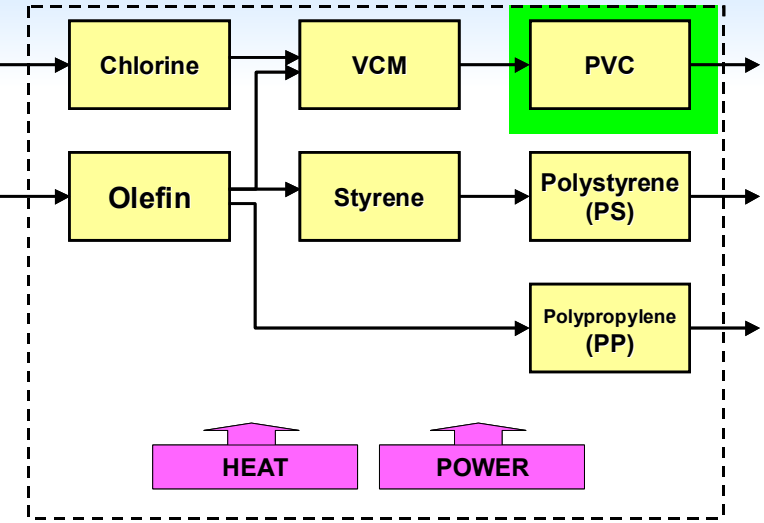
Fuel mix

Select Impact Assessments



Category	Type	Method	Unit	Factor	Selecte
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	
		EI-99 (I)		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 (Jenkings et al. 1999)	lb	Ethylene equiv.	
General	General Impact	EPS (Steen,1999)		elu	

Metrics – Successively Larger Scale



PVC Process

BRIDGESworksMetrics - [Metrics Report]

File Users Window Help

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	**qal**	**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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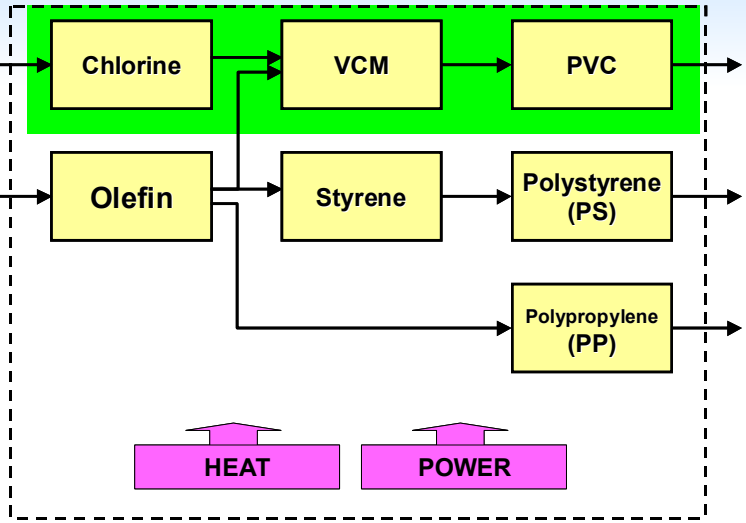
Metrics – Successively Larger Scale



PVC "Group"

BRIDGESworksMetrics - [Metrics Report]

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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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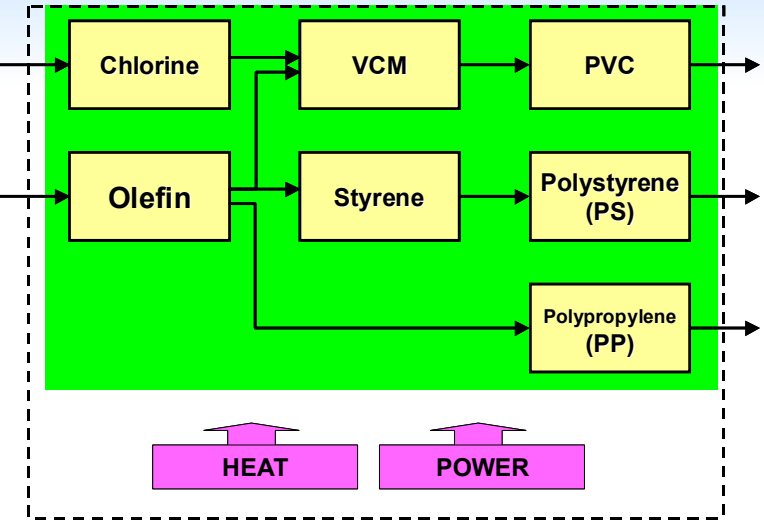
Metrics – Successively Larger Scale



Facility

BRIDGESworksMetrics - [Metrics Report]

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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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BRIDGESworksMetrics - [Metrics Chart]

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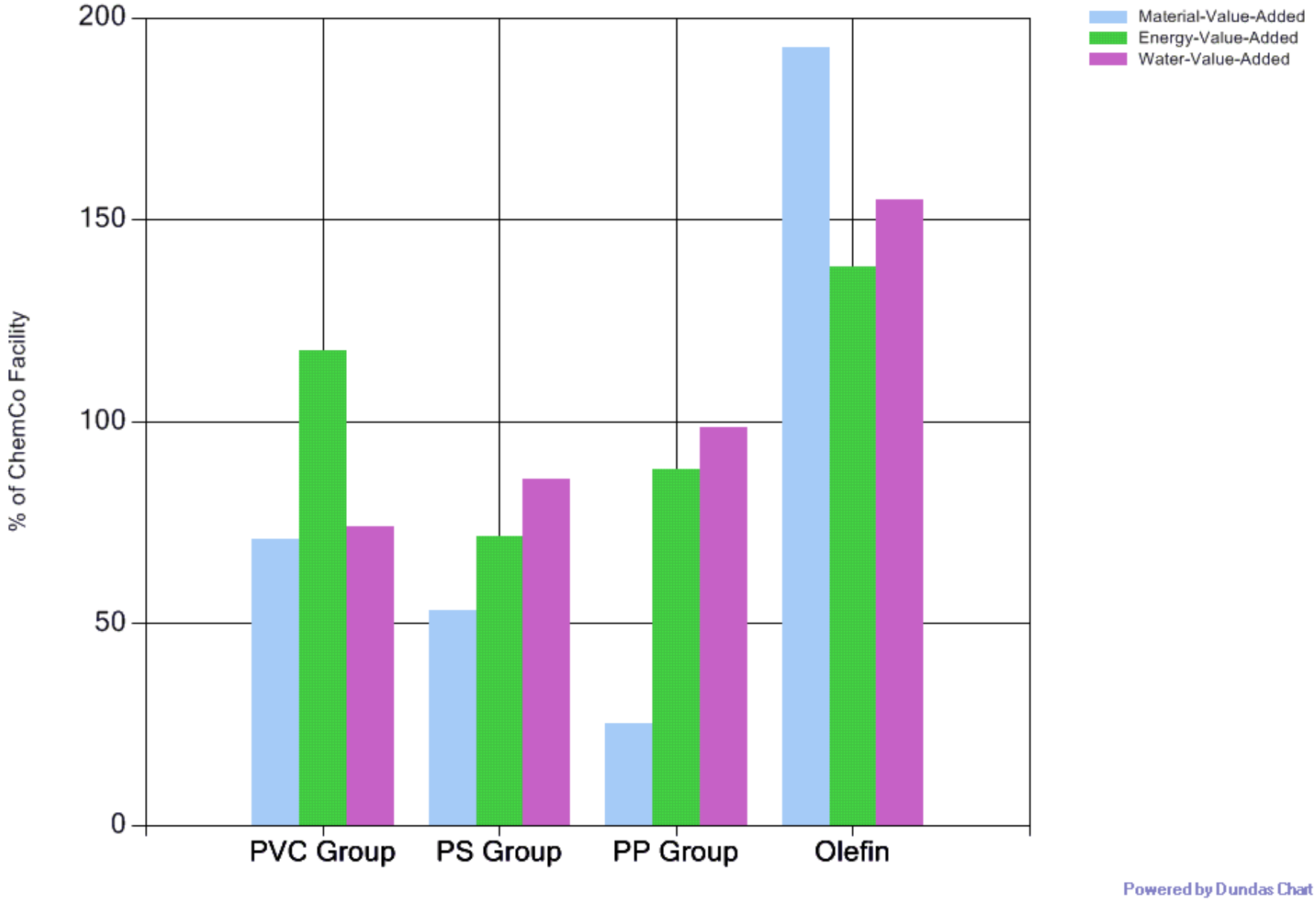
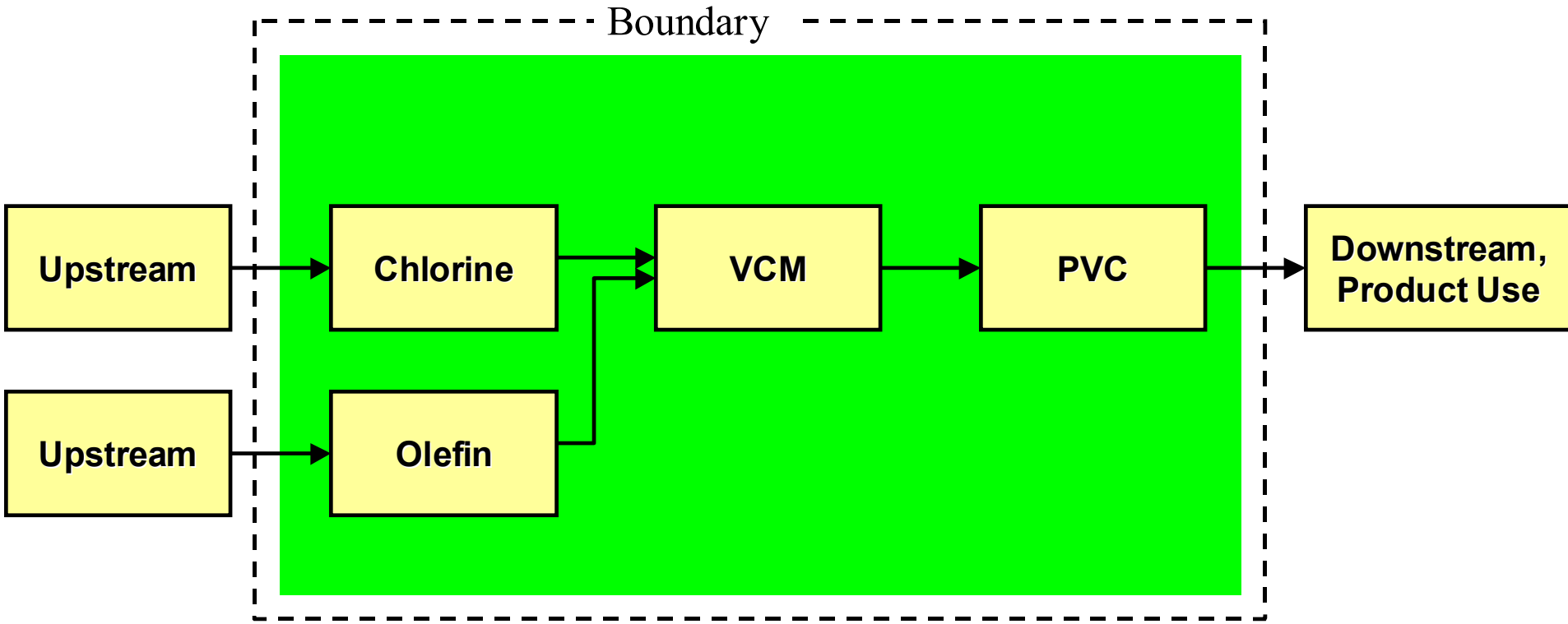
Compare with... | Overall Percentage | Material | Add/Remove Metrics



"Stacking"



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

BRIDGESworksMetrics - [Metrics Chart]

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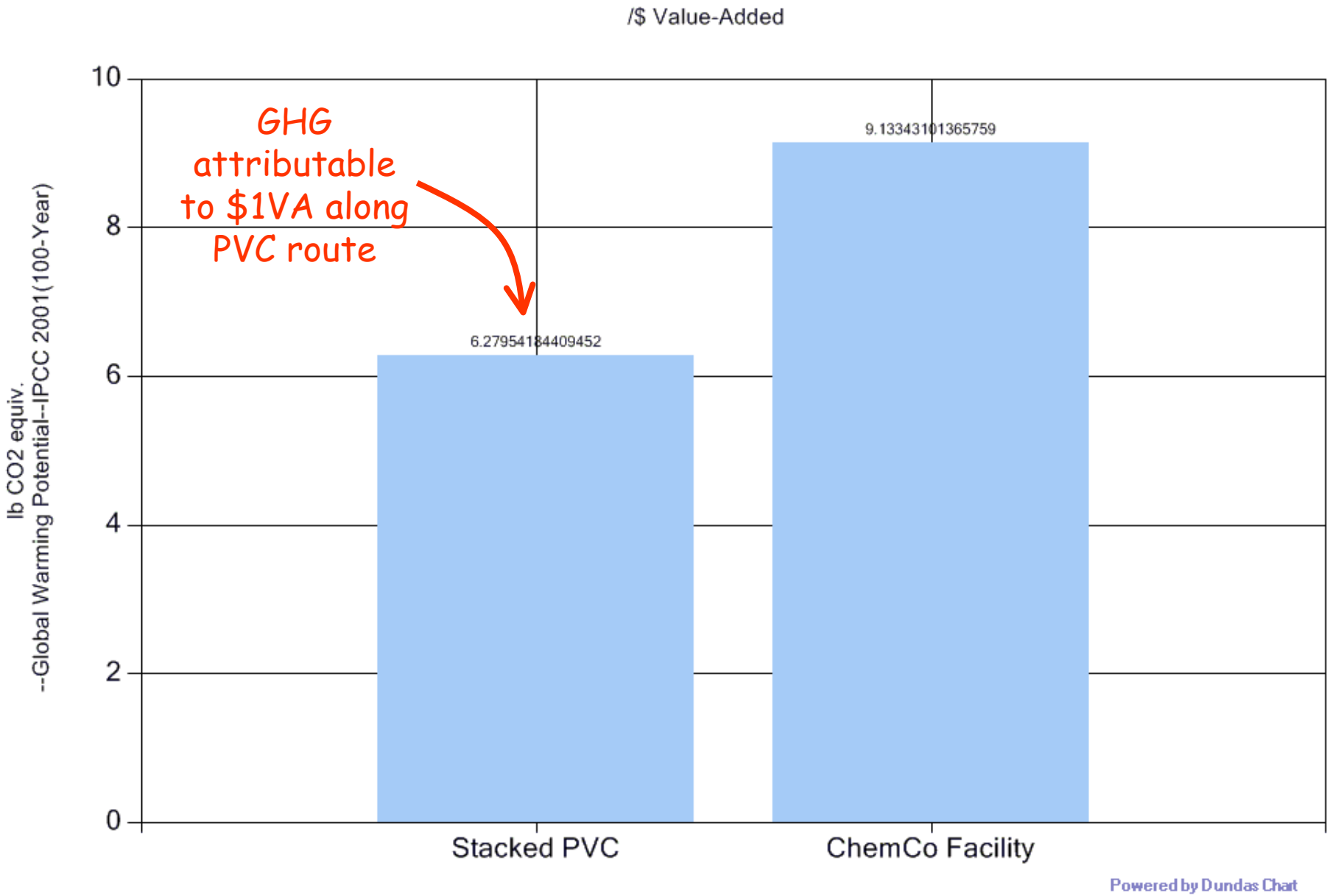
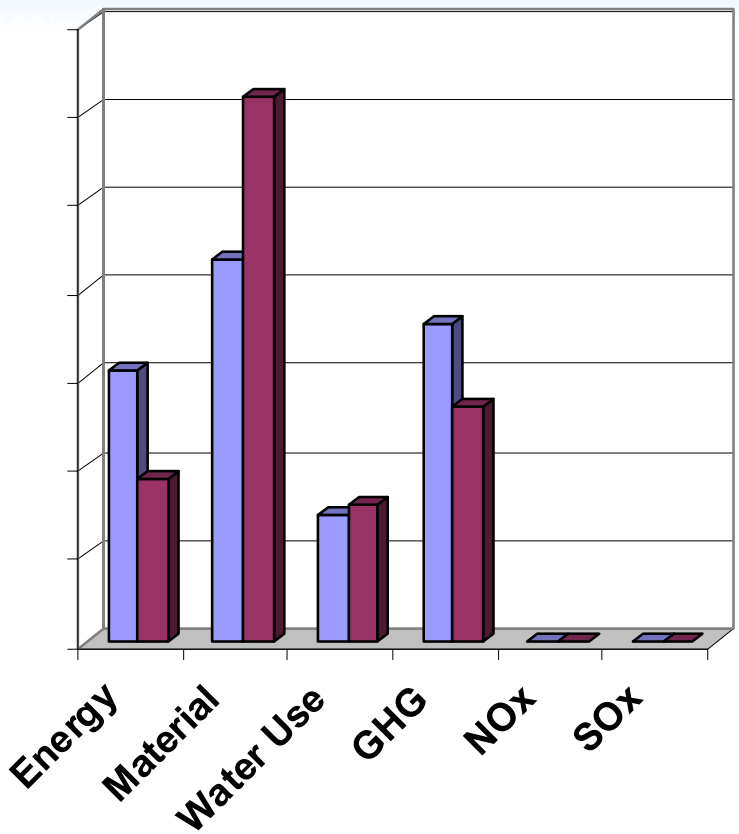
Compare with... | Value Added | --Global Warming Potential--IPCC 2001(100-Year) | Add/Remove Metrics

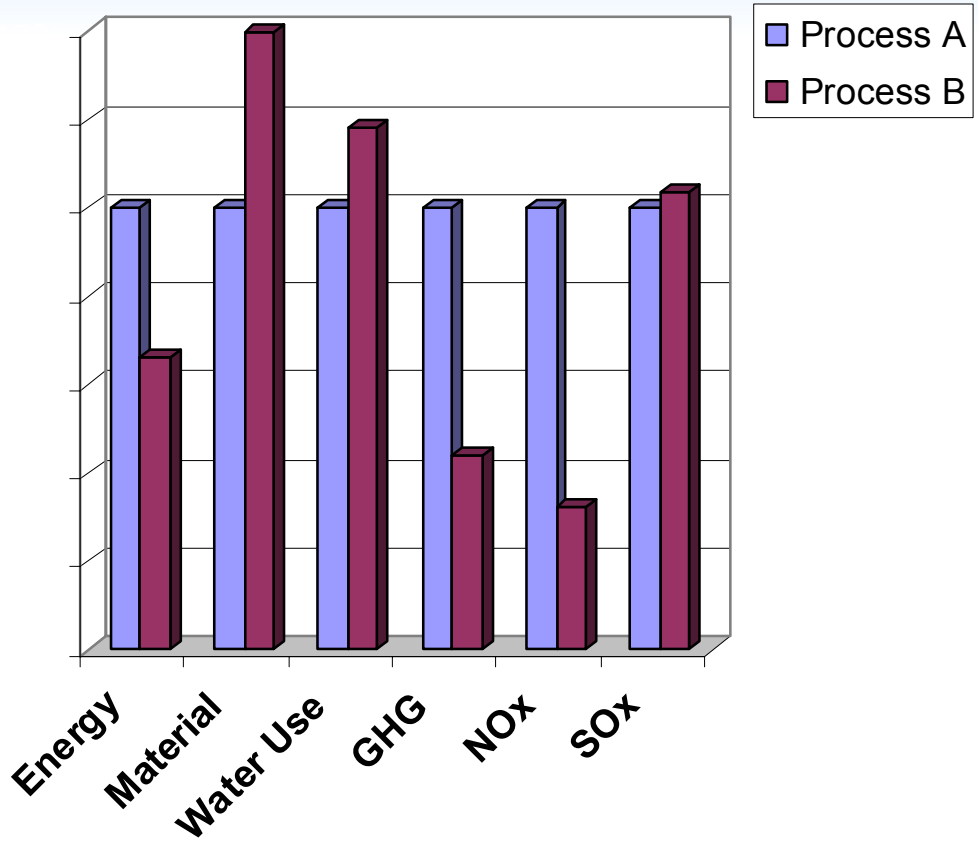


Linking Metrics to LCA

Maleic Anhydride Production



Manufacture Stage

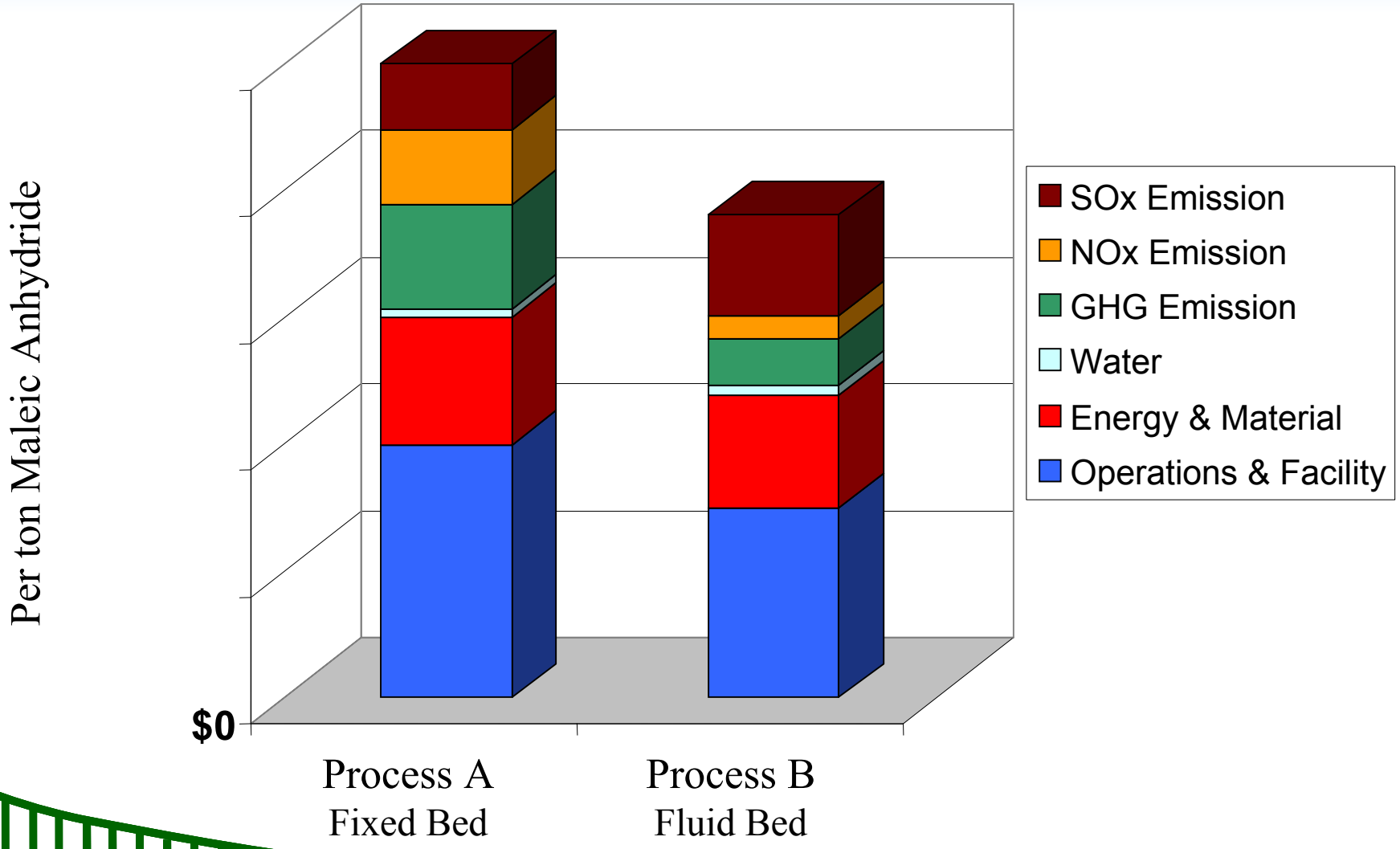


"Cradle-to-Gate"

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



SOx & NOx valuations based on So. California; GHG from IPCC

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