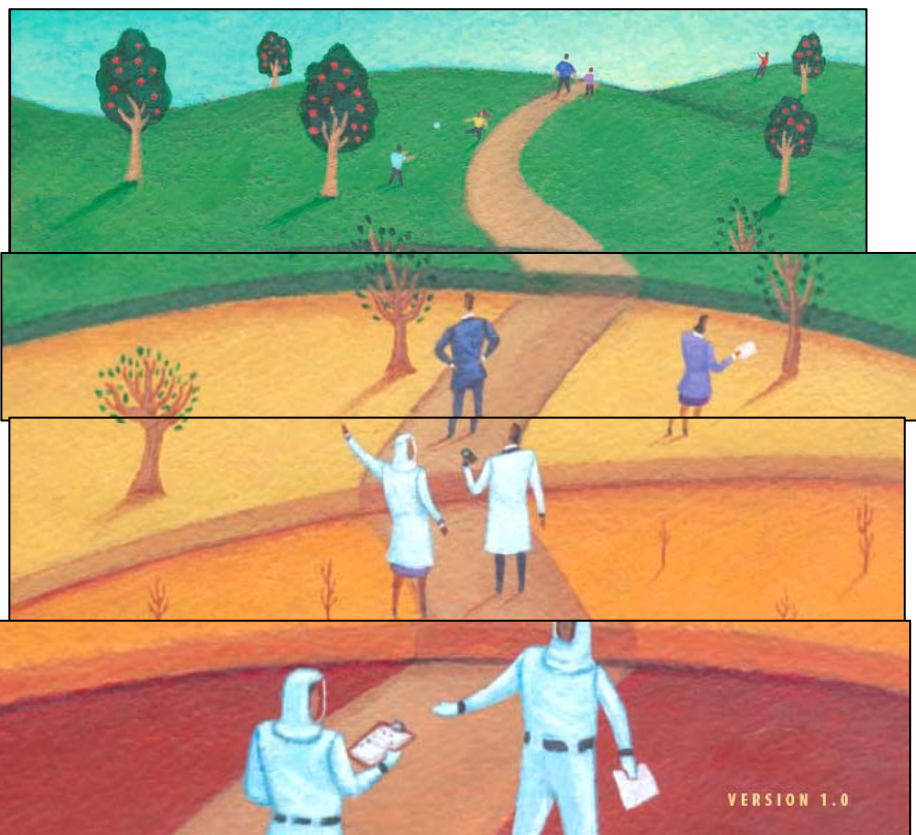


# *Creating a Green Chemistry Metric: The Green Screen for Safer Chemicals*



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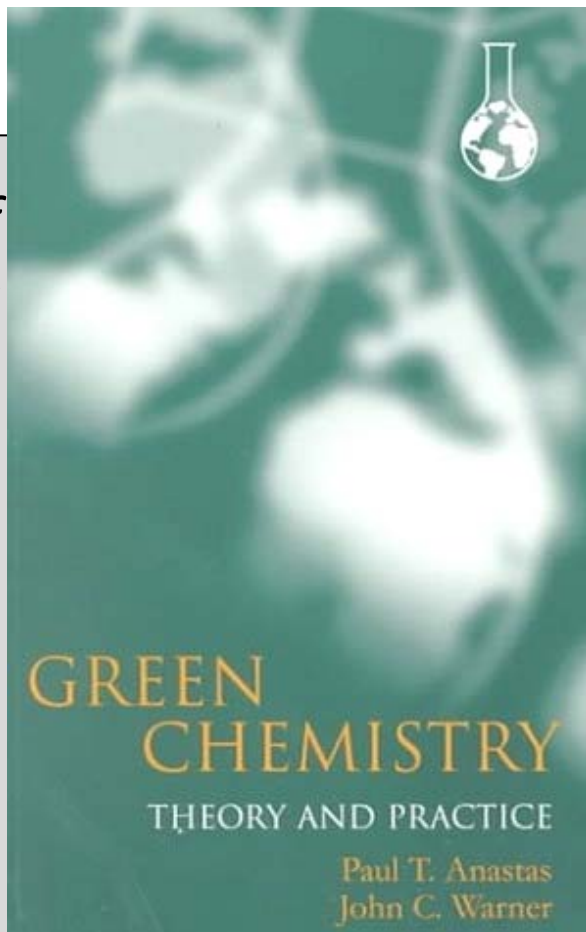
# Why the Green Screen?



- **Defines a path** to greener, safer chemicals
  - Builds from:
    - 12 Principles of Green Chemistry
    - US EPA DfE Alternatives Assessment model
- **Open Source:** transparent + publicly available resource
- **Life cycle thinking**
- Towards agreement on a **method for defining safer, healthier chemicals**



*“the utilization of a set of principles that **reduces the use or generation of hazardous substances** in the design, manufacture and application of chemical products.”*



**#2. Design safer chemicals and products:** Design chemical products to be fully effective, yet have little or no toxicity.

**#10. Design chemicals and products to degrade after use:** Design chemical products to break down to innocuous substances after use so that they do not accumulate in the environment.

**#12. Minimize the potential for accidents**



# Hazard Endpoints

## Human Health Effects

- \*\*\* Carcinogenicity
- \*\*\* Reproductive toxicity
- \*\*\* Developmental tox.
- \*\*\* Genotoxicity  
(mutagenicity)
- \*\*\* Neurotoxicity
- \*\*\* Endocrine disruption
- Systemic toxicity
- Skin Sensitizer
- Acute toxicity
- Corrosion/irritation  
skin/eye
- Immunotoxicity

## Ecotoxicity

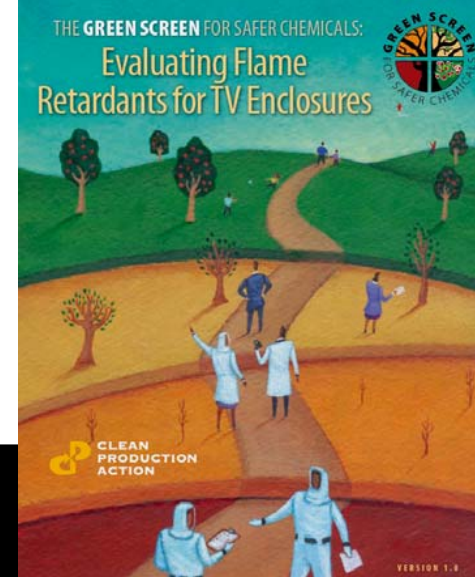
- Acute
- Chronic

## Environmental

- Persistence
- Bioaccumulation

## Physical/Chemical

- Explodability
- Flammability



\*\*\* = Priority Human Health Effect in the Green Screen

# “Priority Effects” – Human Health

- Cancer



- Reproductive/ Developmental Toxicity



- Genotoxicity / Mutagenicity



- Endocrine Disruption



- Neurotoxicity



 = EU, REACH, Article 57

 = US EPA, 40 CFR Part 372, PBT Final Rule (1999)

# Levels of Concern Defined for Each Endpoint

Hazard	Very High (v)	High (H)	Moderate (M)	Low (L)
<b>Environmental Fate</b>				
<b>Persistence—P</b> (half-life in days) <sup>1</sup>	<ul style="list-style-type: none"> <li>• Soil or sediment &gt;180 days; or</li> <li>• Water &gt;60 days</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment &gt;60 to 180 days;</li> <li>• Water &gt;40 to 60 days; or</li> <li>• Potential for long-range environmental transport</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment 30 to 60 days; or</li> <li>• Water 7 to 40 days</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment &lt;30 days;</li> <li>• Water &lt;7 days; or</li> <li>• Ready biodegradability</li> </ul>
<b>Bioaccumulation Potential—B<sup>1</sup></b>	<ul style="list-style-type: none"> <li>• BCF/BAF &gt;5000; or</li> <li>• Absent such data, <math>\log K_{ow} &gt;5</math></li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF &gt;1000 to 5000;</li> <li>• Absent such data, <math>\log K_{ow} &gt;4.5-5</math>; or</li> <li>• Weight of evidence demonstrates bioaccumulation in humans or wildlife</li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF 500 to 1000;</li> <li>• Absent such data, <math>\log K_{ow} 4-4.5</math>; or</li> <li>• Suggestive evidence of bioaccumulation in humans or wildlife</li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF &lt;500; or</li> <li>• Absent such data, <math>\log K_{ow} &lt;4</math></li> </ul>
<b>Ecotoxicity</b>				
<b>Acute Aquatic Toxicity<sup>1</sup></b>		<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} &lt;1</math> mg/l; or</li> <li>• GHS Category 1</li> </ul>	<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} 1-100</math> mg/l; or</li> <li>• GHS Category 2 or 3</li> </ul>	<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} &gt;100</math> mg/l</li> </ul>
<b>Chronic Aquatic Toxicity<sup>1</sup></b>		<ul style="list-style-type: none"> <li>• NOEC &lt;0.1 mg/l; or</li> <li>• GHS Category 1</li> </ul>	<ul style="list-style-type: none"> <li>• NOEC 0.1-10 mg/l; or</li> <li>• GHS Category 2, 3 or 4</li> </ul>	<ul style="list-style-type: none"> <li>• NOEC &gt;10 mg/l</li> </ul>
<b>Human Health</b>				
<b>Carcinogenicity*</b>		<ul style="list-style-type: none"> <li>• Evidence of adverse effects in humans;</li> <li>• Weight of evidence demonstrates potential for adverse effects in humans;</li> <li>• NTP known or reasonably anticipated to be human carcinogen;</li> <li>• OSHA carcinogen;</li> <li>• US EPA known/likely (probable);</li> <li>• California Prop 65;</li> <li>• IARC Group 1 or 2A;</li> <li>• EU Category 1 or 2; or</li> <li>• GHS Category 1A or 1B</li> </ul>	<ul style="list-style-type: none"> <li>• Suggestive animal studies;</li> <li>• Analog data;</li> <li>• Chemical class known to produce toxicity;</li> <li>• US EPA suggested evidence (possible);</li> <li>• IARC Group 2B;</li> <li>• EU Category 3; or</li> <li>• GHS Category 2</li> </ul>	<ul style="list-style-type: none"> <li>• No basis for concern identified or</li> <li>• IARC Group 3 or 4</li> </ul>

# Levels of Concern: Environmental Fate & Ecotoxicity

Hazard	Very High (v)	High (H)	Moderate (M)	Low (L)
<b>Environmental Fate</b>				
<b>Persistence</b> (half-life in days)	<ul style="list-style-type: none"> <li>• Soil or sediment &gt;180 days; or</li> <li>• Water &gt;60 days</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment &gt;60 to 180 days;</li> <li>• Water &gt;40 to 60 days; or</li> <li>• Potential for long-range environmental transport</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment 30-60 days; or</li> <li>• Water 7-40 days</li> </ul>	<ul style="list-style-type: none"> <li>• Soil or sediment &lt;30 days;</li> <li>• Water &lt;7 days; or</li> <li>• Ready biodegradability</li> </ul>
<b>Bioaccumulation Potential</b>	<ul style="list-style-type: none"> <li>• BCF/BAF &gt;5000; or</li> <li>• <math>\log K_{ow} &gt; 5</math></li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF &gt;1000 to 5000;</li> <li>• <math>\log K_{ow} &gt; 4.5-5</math>; or</li> <li>• Weight of evidence demonstrates bioaccumulation</li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF 500 to 1000;</li> <li>• <math>\log K_{ow} &gt; 4-4.5</math>; or</li> <li>• Suggestive evidence of bioaccumulation</li> </ul>	<ul style="list-style-type: none"> <li>• BCF/BAF &lt;500; or</li> <li>• <math>\log K_{ow} &lt; 4</math></li> </ul>
<b>Ecotoxicity</b>				
<b>Acute Aquatic Toxicity</b>		<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} &lt; 1</math> mg/l; or</li> <li>• GHS Category 1</li> </ul>	<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} 1-100</math> mg/l; or</li> <li>• GHS 2 or 3</li> </ul>	<ul style="list-style-type: none"> <li>• <math>LC_{50}/EC_{50}/IC_{50} &gt; 100</math> mg/l</li> </ul>
<b>Chronic Aquatic Toxicity</b>		<ul style="list-style-type: none"> <li>• NOEC &lt;0.1 mg/l; or</li> <li>• GHS Category 1</li> </ul>	<ul style="list-style-type: none"> <li>• NOEC 0.1-10 mg/l; or</li> <li>• GHS 2, 3, or 4</li> </ul>	<ul style="list-style-type: none"> <li>• NOEC &gt;10 mg/l</li> </ul>

# Levels of Concern: Human Health – for example, Cancer

High	Moderate	Low
<ul style="list-style-type: none"> <li>• Evidence of adverse effects in humans</li> <li>• Weight of evidence demonstrates potential for adverse effects in humans</li> <li>• US EPA known/probable</li> <li>• NTP or OSHA</li> <li>• IARC Group 1 or 2A</li> <li>• California Prop 65</li> <li>• EU Category 1 or 2</li> <li>• GHS Category 1A or 1B</li> </ul>	<ul style="list-style-type: none"> <li>• Suggestive animal studies</li> <li>• Analog data</li> <li>• Chemical class known to produce toxicity</li> <li>• US EPA possible</li> <li>• IARC Group 2B</li> <li>• EU Category 3</li> <li>• GHS Category 2</li> </ul>	<p>No basis for concern</p>

GHS = Globally Harmonized System for the Classification and Labeling of Chemicals



## Benchmark 4

**Prefer – Safer Chemical**



## Benchmark 3

**Use but Still Opportunity  
for Improvement**



## Benchmark 2

**Use but Search for Safer  
Substitutes**



## Benchmark 1

**Avoid – Chemical of  
High Concern**



## Benchmark 1

### Avoid – Chemical of High Concern

- a. **PBT** = high Persistence + high Bioaccumulation + high Toxicity
- b. **vPvB** = very Persistent + very Bioaccumulative
- c. **vPT** or **vBT**
- d. **high human Toxicity** for any “priority effect”

*Four hazard criteria for Benchmark 1*

# Breakdown Products

(Principle #10: Design chemicals and products to degrade after use)

- a. PBT
- b. vPvB
- c. vPT or vBT
- d. high human Toxicity



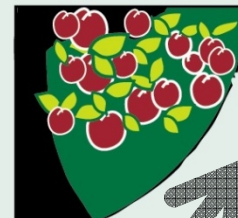
If this chemical and its breakdown products pass all of these criteria, then move on to Benchmark 2

This chemical passes all of the criteria.

## BENCHMARK 4

ready biodegradability (low P) + low B + low Human Toxicity + low Ecotoxicity (+ additional ecotoxicity endpoints when available)

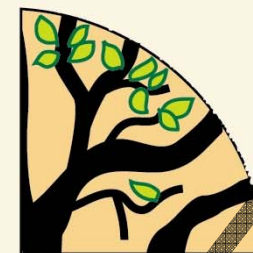
**Prefer—Safer Chemical**



## BENCHMARK 3

- moderate P or moderate B
- moderate Ecotoxicity
- moderate Human Toxicity
- moderate Flammability or moderate Explosiveness

**Use but Still Opportunity for Improvement**



If this chemical and its break-down products pass all of these criteria, then move on to Benchmark 4

## BENCHMARK 2

- moderate P + moderate B + moderate T (moderate Human Toxicity or moderate Ecotoxicity)
- high P + high B
- (high P + moderate T) or (high B + moderate T)
- moderate Human Toxicity for any priority effect or high Human Toxicity
- high Flammability or high Explosiveness

**Use but Search for Safer Substitutes**

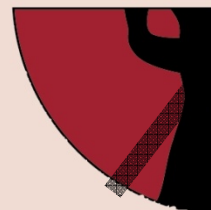


If this chemical and its break-down products pass all of these criteria, then move on to Benchmark 3

## BENCHMARK 1

- PBT: high P + high B + high T<sup>1</sup> (high Human Toxicity<sup>2</sup> or high Ecotoxicity)
- vPvB: very high P + very high B
- vPT (vP + high T) or vBT (vB + high T)
- high Human Toxicity for any priority effect<sup>3</sup>

**Avoid—Chemical of High Concern**



If this chemical and its break-down products pass all of these criteria, then move on to Benchmark 2





# Applying the Green Screen

1. Gather data – no small task!
2. Assign level of concern to each endpoint for each chemical & its breakdown product(s)
3. Run each chemical through the Green Screen to determine chemical Benchmark achieved
4. Benchmark achieved by a chemical & its breakdown products is the lowest Benchmark achieved by either the chemical or a breakdown product



# Green Screen Applied to 3 Flame Retardants for TV Enclosures (& their breakdown products)

## 3 Flame Retardants, including formulation constituents and their breakdown products

- Decabromodiphenyl ether (decaBDE)
- Bisphenol A Diphosphate (BPADP or BAPP)
- Resorcinol bis(diphenylphosphate) (RDP)

# Run Each Chemical through the Green Screen

Chemical	Reason for Benchmark	Stopped by Benchmark ...	
<b>RDP Constituents and Breakdown Products</b>			
<b>CAS# 57583-54-7</b>	<ul style="list-style-type: none"> <li>• H - bioaccumulation</li> <li>• H - chronic ecotox.</li> </ul>	<ul style="list-style-type: none"> <li>• M - persistence</li> <li>• M - systemic + irritation eyes</li> </ul>	Benchmark 2(a), 2(c)
<b>CAS# 98165-92-5</b>	<ul style="list-style-type: none"> <li>• H - persistence</li> </ul>	<ul style="list-style-type: none"> <li>• M - systemic + irritation eyes</li> </ul>	Benchmark 2(c)
<b>CAS# 115-86-6</b> (triphenyl phosphate)	<ul style="list-style-type: none"> <li>• M - bioaccumulation</li> <li>• M - systemic + irritation/corrosion eyes</li> </ul>	<ul style="list-style-type: none"> <li>• H - acute + chronic ecotoxicity</li> </ul>	Benchmark 3(a), 3(b), 3(c)
<b>CAS# 108-95-2</b> (phenol)	<ul style="list-style-type: none"> <li>• H - systemic + irritation/corrosion eyes/skin</li> </ul>		Benchmark 2(d)
<b>CAS# 108-46-3</b> (resorcinol)	<ul style="list-style-type: none"> <li>• M - acute and chronic ecotoxicity</li> <li>• M - endocrine, neurotox., acute, skin sen., irritation/corrosion</li> </ul>		Benchmark 3(a), 3(b), 3(c)
<b>CAS# 838-85-7</b>	<i>(diphenyl phosphate) insufficient data for evaluation</i>		
<b>BPADP (BAPP) Constituents and Breakdown Products</b>			
<b>CAS# 5945-33-5</b>	<ul style="list-style-type: none"> <li>• H - persistence</li> </ul>	<ul style="list-style-type: none"> <li>• M - systemic + irritation eyes</li> </ul>	Benchmark 2(c)
<b>CAS# 83029-72-5</b>	<ul style="list-style-type: none"> <li>• vH - persistence</li> </ul>	<ul style="list-style-type: none"> <li>• M - systemic + irritation eyes</li> </ul>	Benchmark 2(c)
<b>CAS# 115-86-6</b> (triphenyl phosphate)	<ul style="list-style-type: none"> <li>• M - bioaccumulation</li> <li>• M - systemic + irritation/corrosion eyes</li> </ul>	<ul style="list-style-type: none"> <li>• H - acute + chronic ecotoxicity</li> </ul>	Benchmark 3(a), 3(b), 3(c)
<b>CAS# 108-95-2</b> (phenol)	<ul style="list-style-type: none"> <li>• H - systemic + irritation/corrosion eyes/skin</li> </ul>		Benchmark 2(d)
<b>CAS# 80-05-7</b> (BPA)	<ul style="list-style-type: none"> <li>• H - endocrine disruption (emerging: H - repro. + dev.)</li> </ul>		Benchmark 1(d)
<b>CAS# 838-85-7</b>	<i>(diphenyl phosphate) insufficient data for evaluation</i>		
<b>DecaBDE and Breakdown Products</b>			
<b>CAS# 1163-19-5</b> (decaBDE)	<ul style="list-style-type: none"> <li>• vH - persistence</li> <li>• M - cancer, repro., dev., neurological, systemic, endocrine</li> </ul>	<ul style="list-style-type: none"> <li>• M - bioaccumulation</li> </ul>	Benchmark 2(a), 2(c), 2(d)
<b>CAS# 32536-52-0</b> (octaBDE)	<ul style="list-style-type: none"> <li>• vH - persistence</li> </ul>	<ul style="list-style-type: none"> <li>• H - reproductive effects</li> </ul>	Benchmark 1(c)
<b>CAS# 32536-52-0</b> (pentaBDE)	<ul style="list-style-type: none"> <li>• vH - persistence + bioaccumulation</li> <li>• H - acute + chronic ecotox.</li> </ul>	<ul style="list-style-type: none"> <li>• H - systemic organ effects</li> </ul>	Benchmark 1(a), 1(b), 1(c)

# Green Screen Applied to Flame Retardants for TV Enclosures (& their breakdown products)

Chemical	Reasons for Benchmark	Final Benchmark
<b>DecaBDE</b>	<b>Breakdown products:</b> <ul style="list-style-type: none"><li>• <u>pentaBDE</u> = PBT, vPvB, vPT, vBT, + H-endocrine -- Benchmarks 1(a),(b),(c)</li><li>• <u>octaBDE</u> = vPT + H-developmental -- Benchmark 1(c)</li></ul>	Benchmark 1: Avoid - Chemical of High Concern



# Green Screen Applied to Flame Retardants for TV Enclosures (& their breakdown products)

Chemical	Reasons for Benchmark	Final Benchmark
<b>Bisphenol A diphosphate and breakdown products</b>	<u>Breakdown product</u> (and formulation contaminant): <b><i>bisphenol A</i></b> -- high concern for endocrine disruption -- Benchmark 1(d)	Benchmark 1: Avoid - Chemical of High Concern



# Green Screen Applied to Flame Retardants for TV Enclosures (& their breakdown products)

Chemical	Reasons for Benchmark	Final Benchmark
<b>Resorcinol bis(diphenyl phosphate)</b> and breakdown products	<ul style="list-style-type: none"><li>• <u>Chemical constituents</u>: high persistence or bioaccumulation and moderate or high toxicity (but not for priority effects) -- Benchmarks 2(a), 2(c)</li><li>• <u>Breakdown product</u>: <b>phenol</b> -- high toxicity (but not for priority effects) -- Benchmark 2(d)</li></ul>	Benchmark 2: Use <u>but</u> Search for Safer Substitutes





# Conclusions from Green Screen Assessment of FRs for TV Enclosures

- RDP: only flame retardant to pass all criteria under Benchmark 1 of the Green Screen
- An integral element of the Green Screen is taking into account potential breakdown products (degradation products and metabolites).
- The other FRs scored lower on the Green Screen because of concern for their breakdown products.
- **RDP is not a “green chemical”, BUT** it achieves a higher level of human and environmental health and safety than the alternatives. Thus RDP (and its breakdown products), based upon a Green Screen assessment, is a more preferable for TV enclosures.



# Who Is Using the Green Screen?

**Government agencies (WA, ME)** to identify safer alternatives to chemicals of high concern in flame retardants and toys

- *“We reviewed toxicity evaluation protocols and determined that Green Screen was the most comprehensive and best fit Ecology’s interests” – Alex Stone, Senior Chemist, WA State Department of Ecology*
- **WA State’s Conclusions from the use of the Green Screen**
  - Proves to be a valuable tool to evaluate toxicity of different chemicals
  - Fulfills a vital portion of the state’s Safer Chemical Alternative Process
  - Will be used by Ecology as the primary methodology for evaluating toxicology when assessing safer chemical alternatives



# Who Is Using the Green Screen?

**Original Equipment Manufacturers (OEMs)** to identify the availability of safer alternatives to chemicals of high concern – want to avoid “going out of the frying pan and into the fire”

- Incorporating Green Screen into corporate substances of concern process
- Helps to avoid multiple substitutions
- Anticipates legislation

**Retailers** to screen products

**Clean Production Action is working with business and university partners** to create an external repository of Green Screen assessments



# For Copies of the Green Screen...

[www.cleanproduction.org/Green.GreenScreen.php](http://www.cleanproduction.org/Green.GreenScreen.php)

