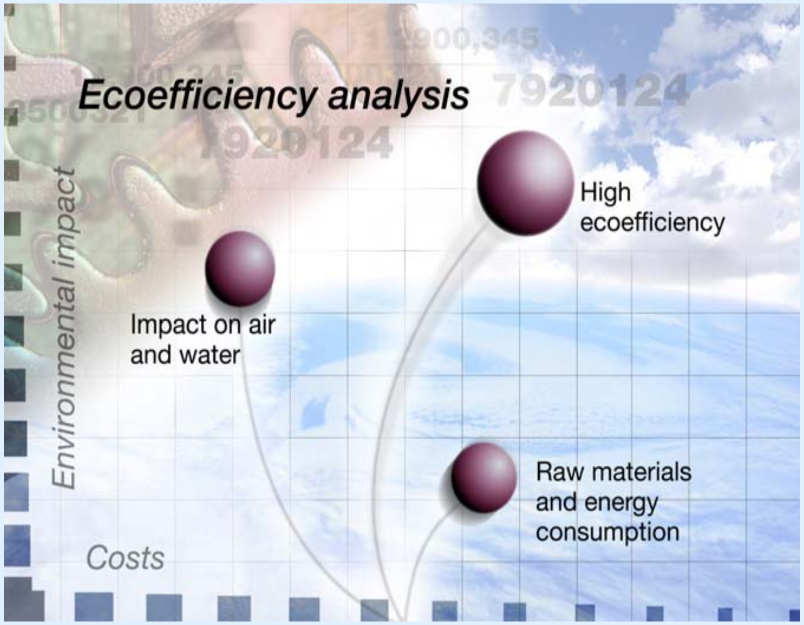
Residential Insulation Systems



Validated
Ecoefficiency
Analysis
Method

Project Partners

Mary Poma	KUN/S
Michael Krupa	KUN/S
Jeff Harper	KUN
Bill Robert	NTU/R
Chris Bradlee	NTU/R
Chris Fennell	BuildingInsight, LLC

Bruce Uhlman, NTU/R, BASF Corporation
April 2008

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Final Report

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Overall Results

Individual Results

Summary

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- This study compares different insulating systems for residential housing. The base case considers a residential home in Newark, NJ (Zone 4) with a traditional roof and walls consisting of:
  - Structural insulated panel systems (SIPs) using EPS
  - Structural insulated panel systems (SIPs) using PU Foam
  - 2X4 stick construction with fiberglass BATT
  - 2x6 stick construction with fiberglass BATT

  Scenarios consider:
  - Energy and cost calculations for Minneapolis, Minnesota (Zone 6)
  - Energy and cost calculations for Las Vegas, Nevada (Zone 3)
  - Energy and cost calculations for Tampa, Florida (Zone 2)

Summary

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- The newer construction techniques: structural insulated panels (both EPS and PU SIP) provide environmental and cost benefits thanks to reducing heating and cooling loads over the lifetime of the home. The life-time energy savings outweigh the higher installed costs of these systems for all scenarios analyzed in this study.
- PU and EPS SIP are consistently the most eco-efficient technology. In addition to providing energy efficiency benefits, they have low environmental impact over their life cycle.
- Stick built technology, specifically, 2x4 framing with FG BATT insulation is the least eco-efficient technology due to its low thermal efficiency.

Objectives and Planned Use of the Study

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Objective of the study

This eco-efficiency analysis compares the environmental impacts and the costs from all life-cycle stages for different residential insulating systems.

Use of the study

- Customer Marketing

Target groups for the study

- Builders
- Homeowners

Limits and restrictions for the use of the results

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- The LCA-calculations are set up according to the rules and principles of the ISO 14040 -14044. The BASF methodology also includes the impact areas of risk and toxicity as well as life cycle costing.
- The eco-efficiency analysis includes additional features designed to assist the decision making process e.g. portfolio, fingerprint.
- The results are valid only for the alternatives & system boundary conditions considered in the analysis, the defined customer benefit, and other study assumptions identified.

Residential Insulating Systems

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Customer benefit (CB)	BASF alternatives	Comparable alternatives
Construction, use & disposal of the walls and roof of a single story residential home in Newark, NJ, over 60 years.	2x4 truss roof construction with: •SIP walls (3.5” EPS, R=16.9) • SIP walls (3.5” PU, R=22.2)	2x4 truss roof construction with: •2x4 wall system (FG batt, 16”o.c., R=13.2) •2x6 wall system (FG batt, 24” o.c., R=19.3)

Wall Construction

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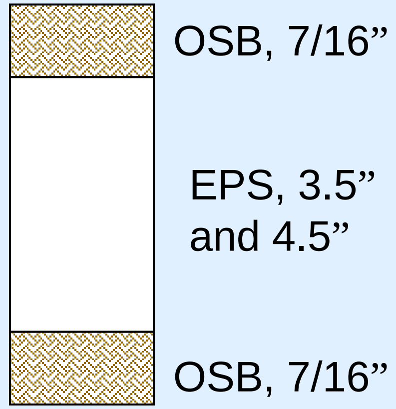
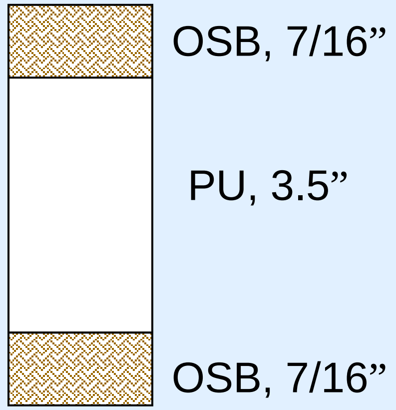
SIP - EPS

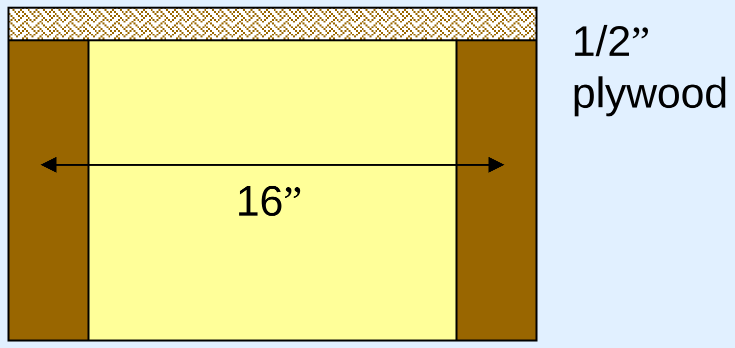


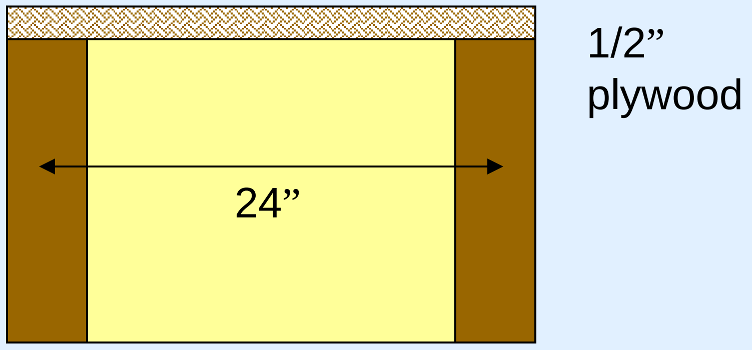
Framing Factors

• SIPS	5 %
• 2x4	14 %
• 2x6	11 %

SIP - PU







System boundaries for Structurally Insulated Panel Systems (PU SIPs)

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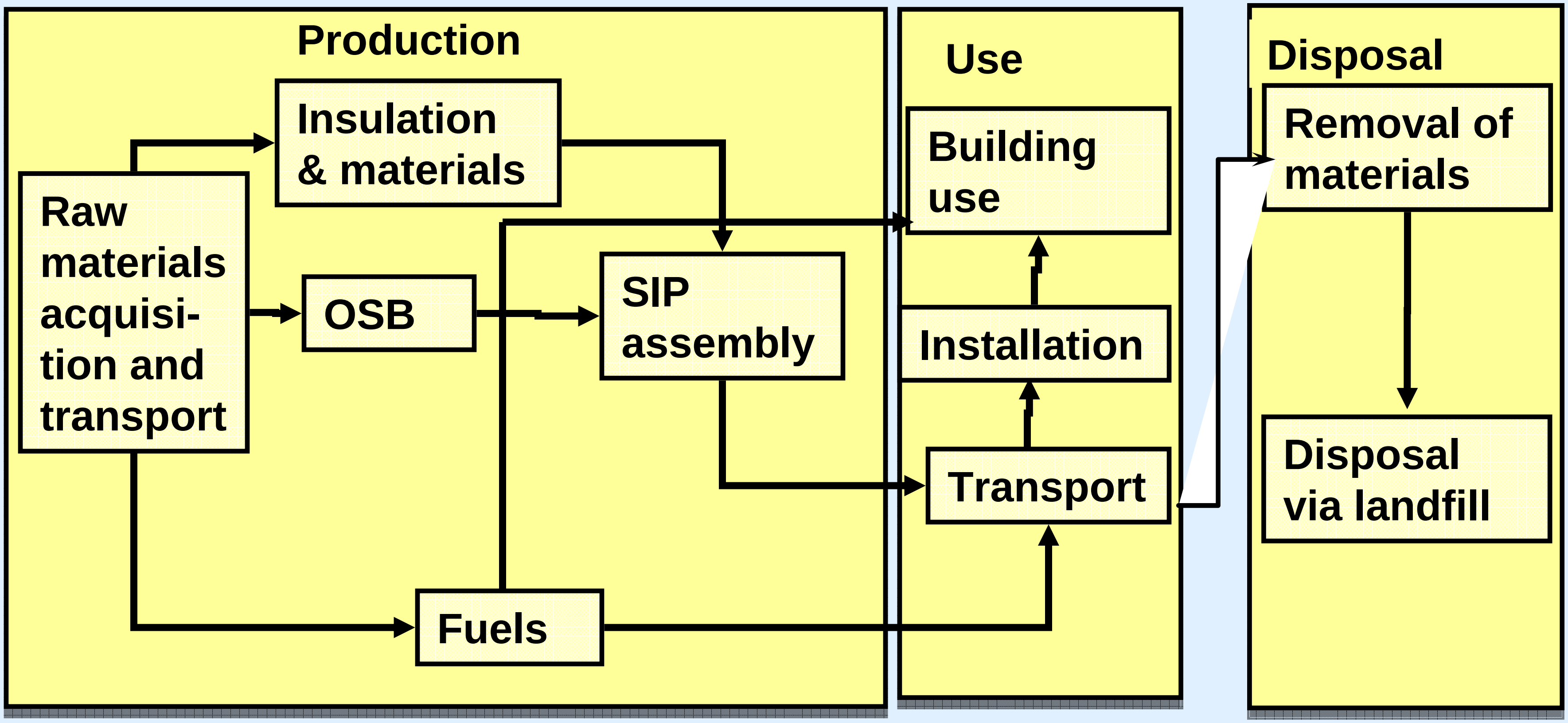

System boundaries for Structurally Insulated Panel Systems (EPS SIPs)

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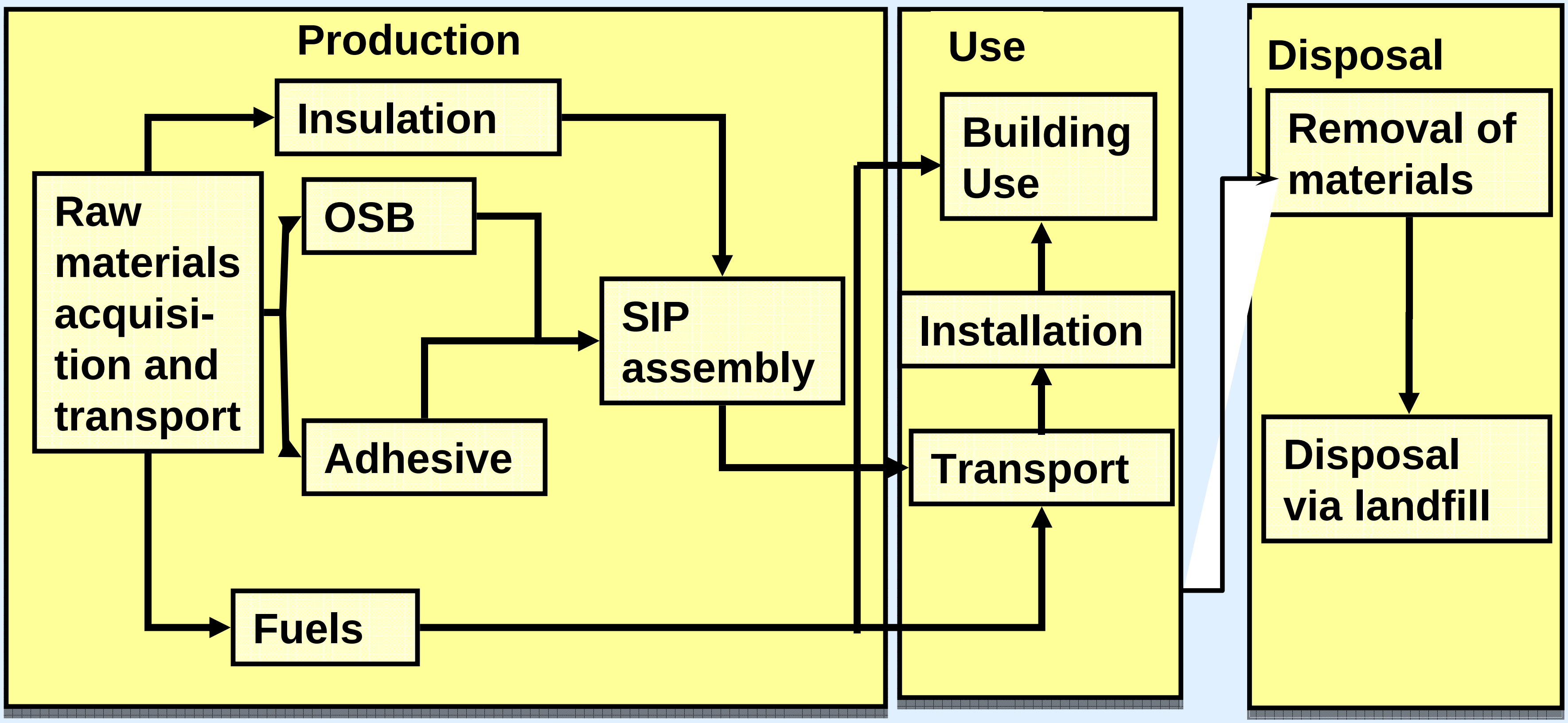

Production

Raw materials acquisi-tion and transport

Insulation

OSB

Adhesive

SIP assembly

Fuels

Use

Building Use

Installation

Transport

Disposal

Removal of materials

Disposal via landfill

System boundaries for wood construction (2” x 4” or 2” x 6” construction)

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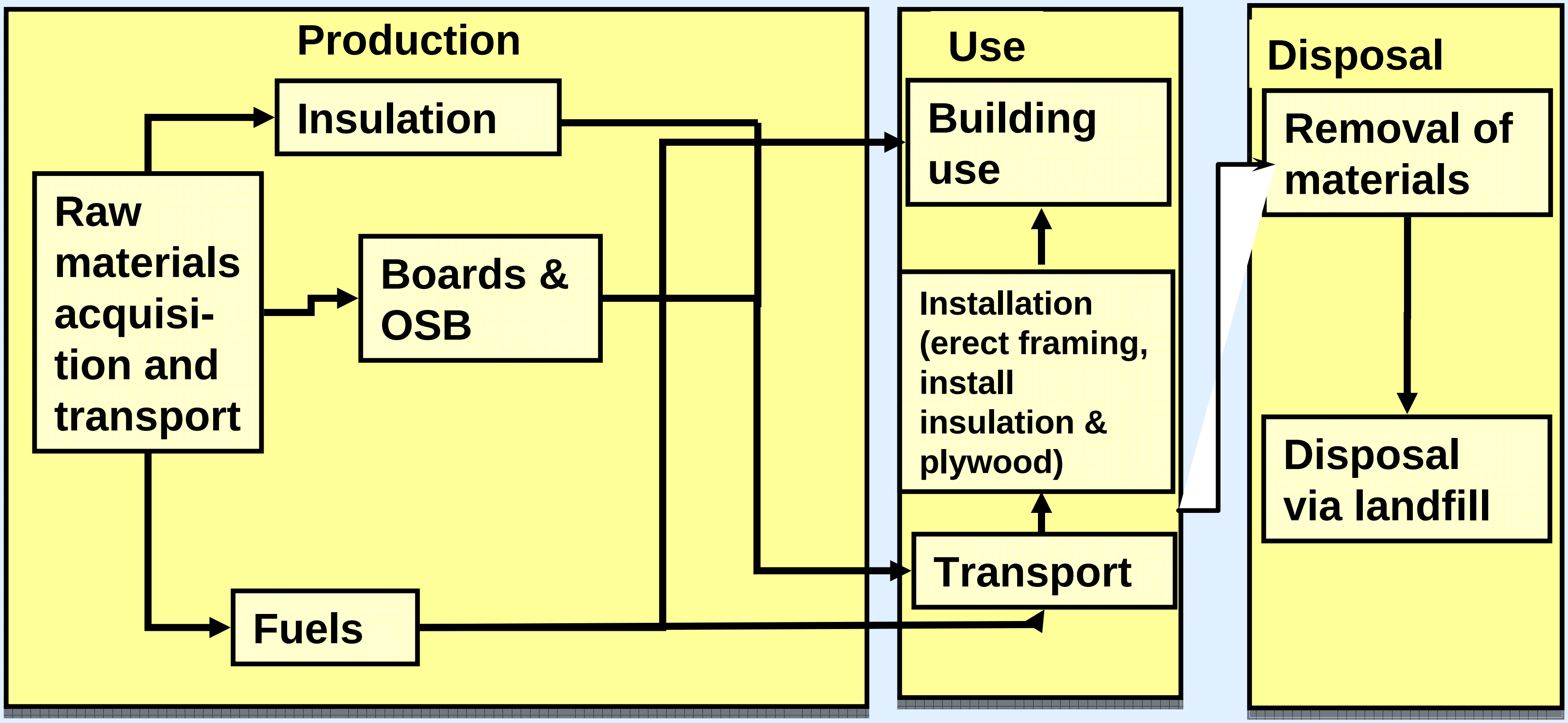

Production

Insulation

Raw materials acquisi-tion and transport

Boards & OSB

Fuels

Use

Building use

Installation (erect framing, install insulation & plywood)

Transport

Disposal

Removal of materials

Disposal via landfill

General assumptions I

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- Base case considers a one-story home in Newark, NJ with the following design parameters:
  - floor area of 1,100 ft^2 (single zone; 27 ft. x 41 ft.)
  - R38 attic insulation
  - R13 wall insulation
  - Aspect ratio 1.5
  - 8 ft. ceiling height
  - Home life of 60 years with HVAC cycle of 15 years. HVAC is DX: direct compression with gas furnace
  - SEER rating of 13
  - Furnace efficiency of 90%
  - Electricity cost is $0.1444/kWh and natural gas is $1.43/Therm
  - Location factor of 1.106 for costing
- The following design parameters are adjusted for each scenario:
  - Regional utility pricing (electricity and natural gas)
  - Regional material and building costs
  - Climate data used for energy modeling
  - Building Insulation requirements (wall and roof system)

General assumptions II

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- Scenarios/Locations considered: Tampa, Florida., Minneapolis, Minnesota, Las Vegas, Nevada.
  - Consideration of local weather, building code and cost data
- ELA (Effective Leakage Area) was defined for each wall system. Tight systems (e.g. SIP construction) were give a value of 27% of standard stick construction.
  - No effect on HVAC efficiencies between standard and tight wall systems.
- Transportation distances for all materials except concrete and wood are set at 500 miles from manufacture to job-site. In practice distances will vary. Wood distance set at 200 miles as an average.
- Wall maintenance includes replacement of 5% of materials every 30 years for stick and every 50 years for SIP systems.
- Resistance to weather damage during the home use phase is assumed to be the same. In practice, typical construction techniques using 2x4 and 2x6 stick construction will likely not be as resistant as the SIP wall systems.
- LTTR (long-term thermal resistance) values used for insulation.   For PU-SIP, initial R value is approximately 7, while an aged value of 5.9 was used for the energy modeling (range 5.6 – 6.2).

General assumptions III

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- Leakage rate of blowing agent from PU SIP foam considered in air emissions impact (7% initial loss during blowing then 0.5%/year).
- R-value for EPS selected as 4.
- Differences between installation and life-cycle costs for each system are considered (Incremental cost vs. lowest alternative will be used).
- Initial costs include material & labor for the framing, insulation & HVAC systems.
- Life-cycle costs are included for natural gas heating, electrical cooling, and HVAC replacement.
- All systems have the same interior and exterior coverings.
- Costs for routing electric utilities are assumed to be the same for all systems.
- Energy10 v.1.8 developed by NREL under funding from the DOE will be used for the energy and life cycle cost modeling.
- Differences in energy consumption for heating/cooling the house vs. the minimum achieved over the defined lifetime will be used for life cycle environmental impact.

Input Data I

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Input data cells

Home dimensions

Zone - City		**4**	**Newark**	
Stories		1		
Floor dimensions	ft	27.1	by	40.6
Floor to ceiling height	ft	8.0		
Floor to top of roof	ft	14.6		
Floor Area	ft2	1100		
Surface Area	ft2	3283		
Wall gross area	ft2	1083		
Roof gross area	ft2	1100		
Window gross area	ft2	240		
% wall area uninsulated	%	20%		
Time period to consider	years	60		

	Name:	**SIP-EPS**	**SIP-PU**	**2x4 Stick**	**2x6 Stick**
Wall system selection	**Units**				
Walls		**SIP-EPS**	**SIP-PU**	**2X4 FG BATT**	**2X6 FG BATT**
R-value used for energy calculations	BTU-in/ft2/h/deg F	16.9	22.2	13.2	19.3
Maintenance Interval	years	50	50	30	30
Replacement factor	%	5%	5%	5%	5%
Insulation density	lb/ft3	1.0	2.3	1.4	1.4
Roof system selection					
Roof		**Truss R-38**	**Truss R-38**	**Truss R-38**	**Truss R-38**
R-value used for energy calculations	BTU-in/ft2/h/deg F	38.0	38.0	38.0	38.0
Maintenance Interval	years	25.0	25.0	25.0	25.0
Replacement factor	%	10%	10%	10%	10%
Insulation density	lb/ft3	1.4	1.4	1.4	1.4

Input Data II

Final Report

System Materials		SIP-EPS	SIP-PU	2x4 Stick	2x6 Stick
Wall System					
Insulation					
EPS	kg	117	0	0	0
Polyiso	kg	0	271	0	0
Fiberglass BATT	kg	0	0	139	233
Concrete	kg	0	0	0	0
Monocrete®	kg	0	0	0	0
OSB	kg	812	812	486	486
Wood	kg	0	0	1270	1482
Rebar	kg	0	0	0	0
Steel framing	kg	0	0	0	0
Cinderblock	kg	0	0	0	0
Adhesive	kg	11	0	0	0
Roof System					
Insulation					
EPS	kg	0	0	0	0
Polyiso	kg	0	0	0	0
Fiberglass BATT	kg	1455	1455	1455	1455
OSB	kg	1162	1162	1162	1162
Wood	kg	1567	1567	1567	1567
Rebar	kg	0	0	0	0
Steel framing	kg	0	0	0	0
Cinderblock	kg	0	0	0	0

Input Data III

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Energy Consumption

Annual energy consumption		SIP-EPS	SIP-PU	2x4 Stick	2x6 Stick
Natural Gas	KBTU/y	51197	49162	73461	71125
	MJ/y	54013	51866	77501	75037
Difference from minimum used	MJ/y	2147	0	25635	23171
Electricity	KWhr/y	6052	6027	6057	6117
	MJ/y	21787	21697	21805	22021
Difference from minimum used	MJ/y	90	0	108	324
Total energy consumption over time period considered					
Natural Gas	MJ/CB	128,816	-	1,538,127	1,390,258
Electricity	MJ/CB	5,400	-	6,480	19,440
Total	MJ/CB	134,216	-	1,544,607	1,409,698

Installation and Use Costs

		SIP-EPS	SIP-PU	2x4 Stick	2x6 Stick
Life cycle cost Results					
Initial wall framing and insulation cost	$/CB	$ 8,249	$ 9,489	$ 4,039	$ 4,309
Initial roof framing and insulation cost	$/CB	$ 10,643	$ 10,643	$ 10,643	$ 10,643
Initial HVAC cost	$/CB	$ 9,080	$ 8,964	$ 9,746	$ 9,689
Utilities	$/CB	$ 72,491	$ 71,083	$ 85,591	$ 84,665
HVAC replacement	$/CB	$ 11,853	$ 11,702	$ 12,722	$ 12,649
Total Life Cycle Costs	$/CB	$ 112,316	$ 111,882	$ 122,741	$ 121,955
Cost difference vs least expnsive	$/CB	$ 434	$ 0	$ 10,860	$ 10,073
Use for EE Calc		$ 434	$ 0	$ 10,860	$ 10,073

Input Data IV

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Installed Costs Including Material and Labor

Wall systems	2X4 FG BATT 16" O.C.	2X6 FG BATT 24" O.C.	SIPS- PU 3.5"	SIP-EPS 3.5"	SIP-EPS 4.5"
$/ft^2 gross wall area	$3.15[1]	$3.36[1]	$7.80[3]	$6.78[2]	$7.46[2]
Roof Systems	**2x4 FG BATT R30**	**2x4 FG BATT R38**	**2x4 FG BATT R49**		
$/ft^2 floor area	$8.13[1]	$8.30[1]	$8.75[1]		

[1] 2006 RSMeans National Average costs. Adjustments required for regional location factors as well as price escalation.

[2] EPS SIP manufacturer (confidential, 2008)

[3] Best Estimate based on SIP-EPS pricing (15% cost escalation)

Abbreviations

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- CB – Customer Benefit (i.e. functional unit analyzed)
- SIP - Structural Insulated Panels
- OSB - Oriented strand board
- FG BATT – Fiber Glass BATT

Results

Base Case: Residential Insulation

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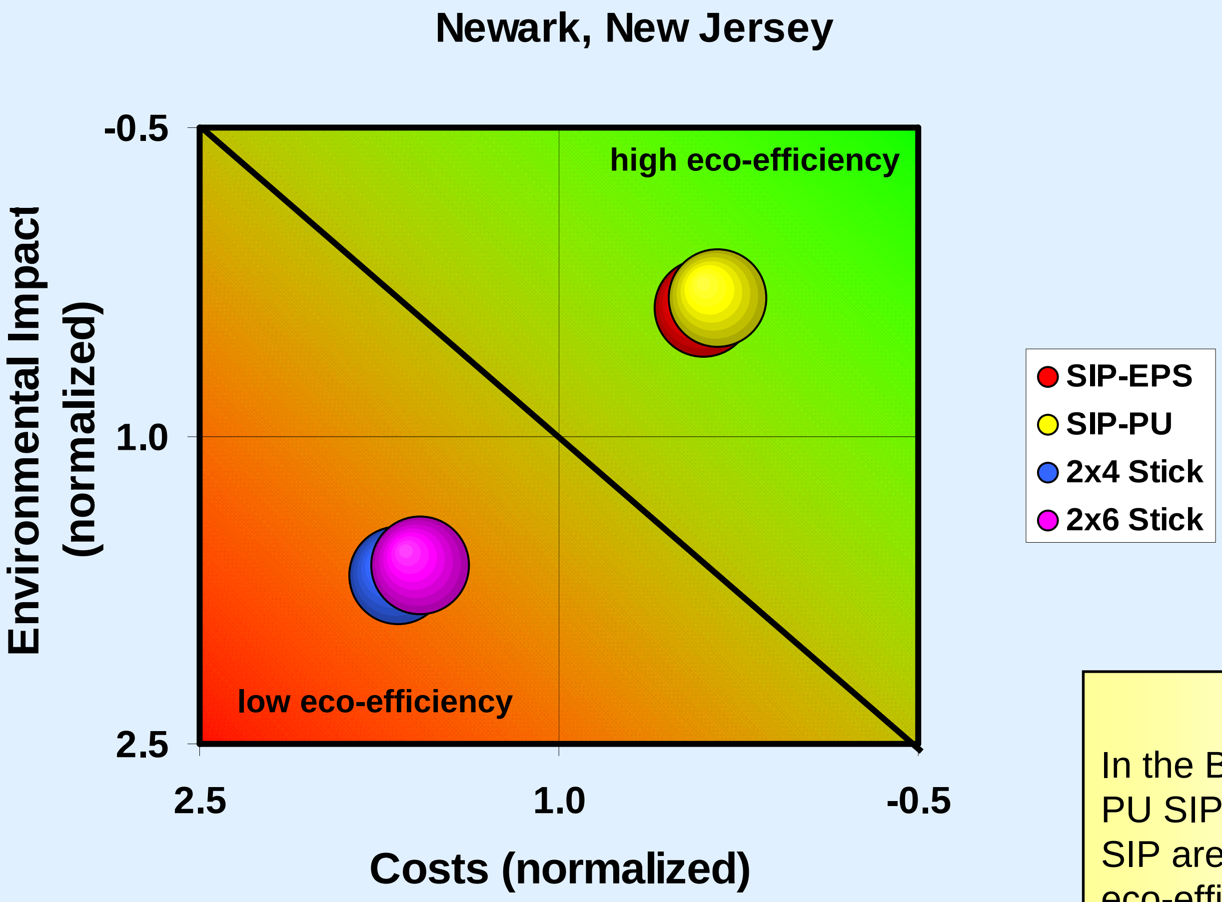
Customer Benefit (CB):

•Construction, use & disposal of the walls and roof of a single story residential home in Newark, NJ, over 60 yrs.



In the Base case PU SIP and EPS SIP are of similar eco-efficiency

Eco-Efficiency

Life cycle costs

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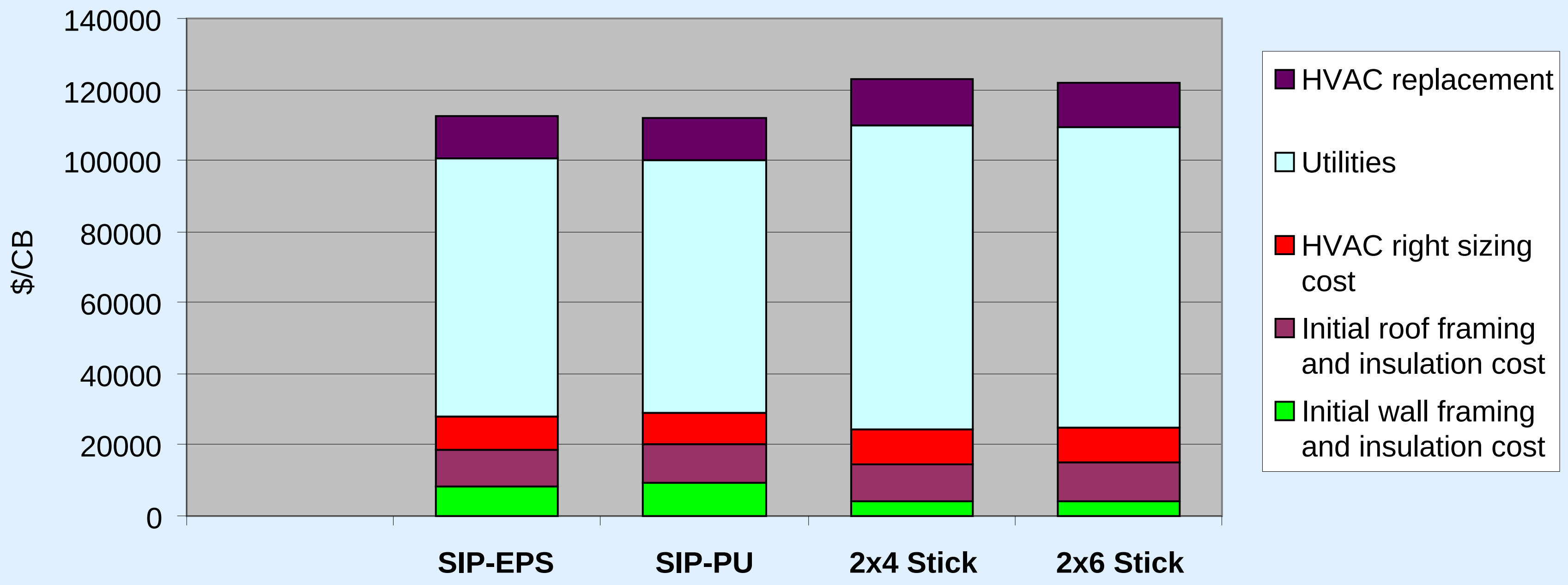

The lifetime utility costs are the most significant.

Eco-Efficiency

Life cycle costs – construction trade-offs (differences to lowest cost alternative)

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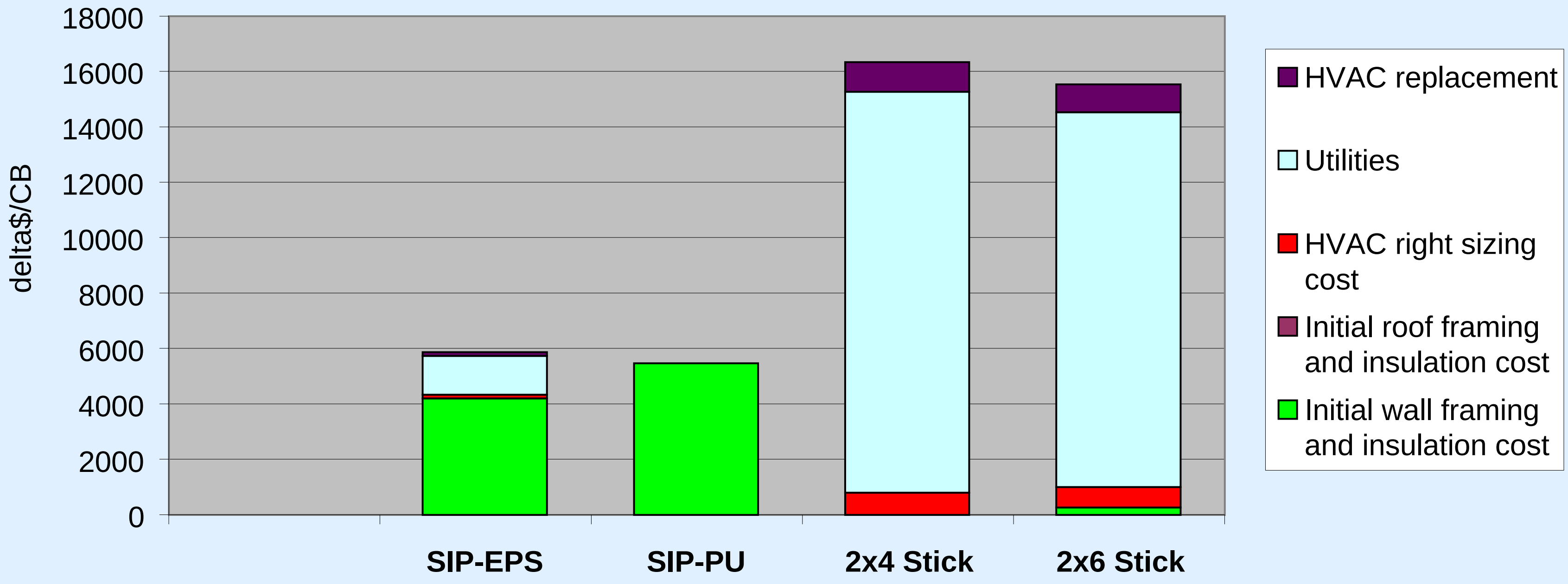

Wall framing and insulation costs are significant, and are lowest for 2x4 stick construction. However, lifetime utility costs are the biggest differentiator and are lowest for the PU SIP alternative.

Ecological Fingerprint

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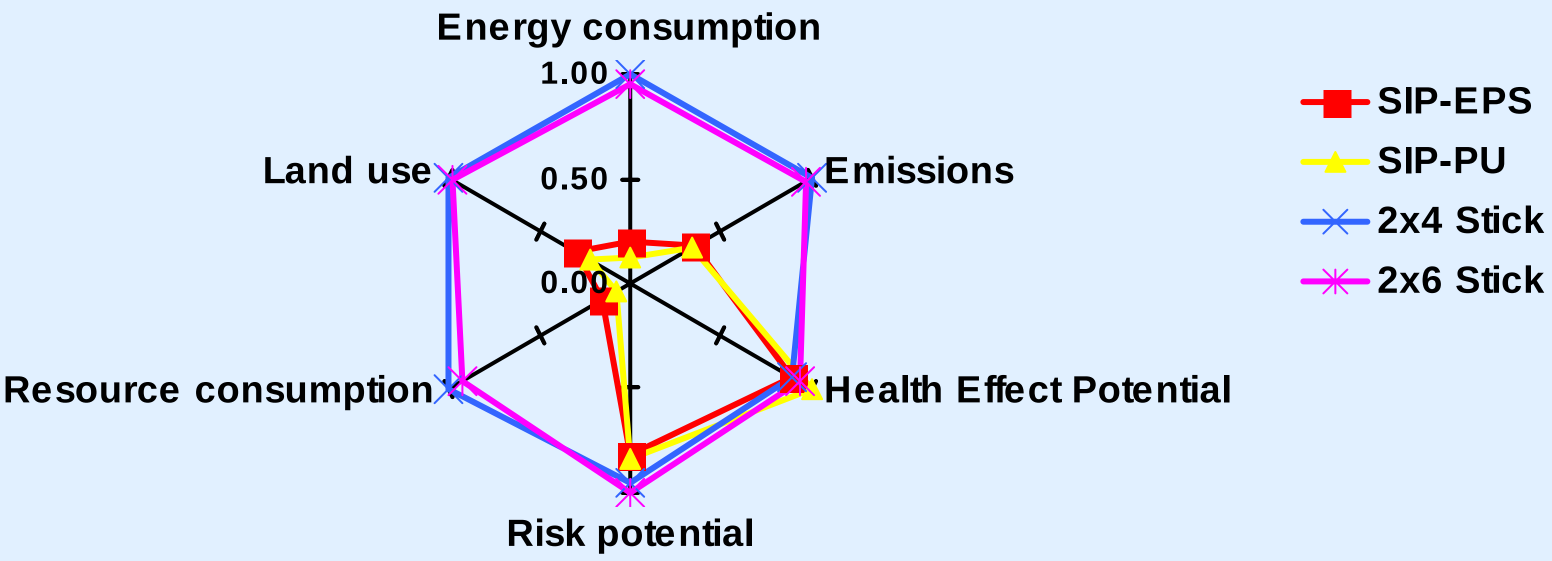

1,0 = worst position, better results ordered relatively <1

Eco-Efficiency

Comments to the Ecological Fingerprint

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- 2x4 stick construction has the highest environmental impact in all categories except risk and health effect potential. The high impact is due to this system having the lowest R value (13.2), and the high rate of air leakage through the system, which results in low thermal efficiency and high consumption of fuel and electricity for heating and cooling over the lifetime of the home. In risk potential, the stick construction techniques have slightly higher impact because more maintenance is required. Along with EPS-SIPS, 2x4 has the lowest health effect potential.
- 2x6 stick construction also has high impact in all categories. Although the system R value (19.3) is greatly improved over the 2x4 stick construction and even better than the EPS SIP, the system still has high air leakage rates which plays a significant role in high fuel and electricity consumption for heating and cooling. Large material requirements also negatively impact several impact areas.
- The PU SIP system‘s high R value (22.2) combined with low air leakage rates greatly improves environmental impact due to heating and cooling of the home. This alternative has the lowest overall environmental impact in energy use, resource consumption, emissions and land use. The isocyanate contributes to this alternative having the highest health effect potential.
- The EPS SIP has the lowest environmental impacts in health effect potential and risk potential. Though it has a moderate system R value (16.9) it‘s low air leakage leads to low fuel and electricity consumption for HVAC. It also has a light system weight resulting in low health effect potential, and low impact on the production of construction materials.

Energy consumption

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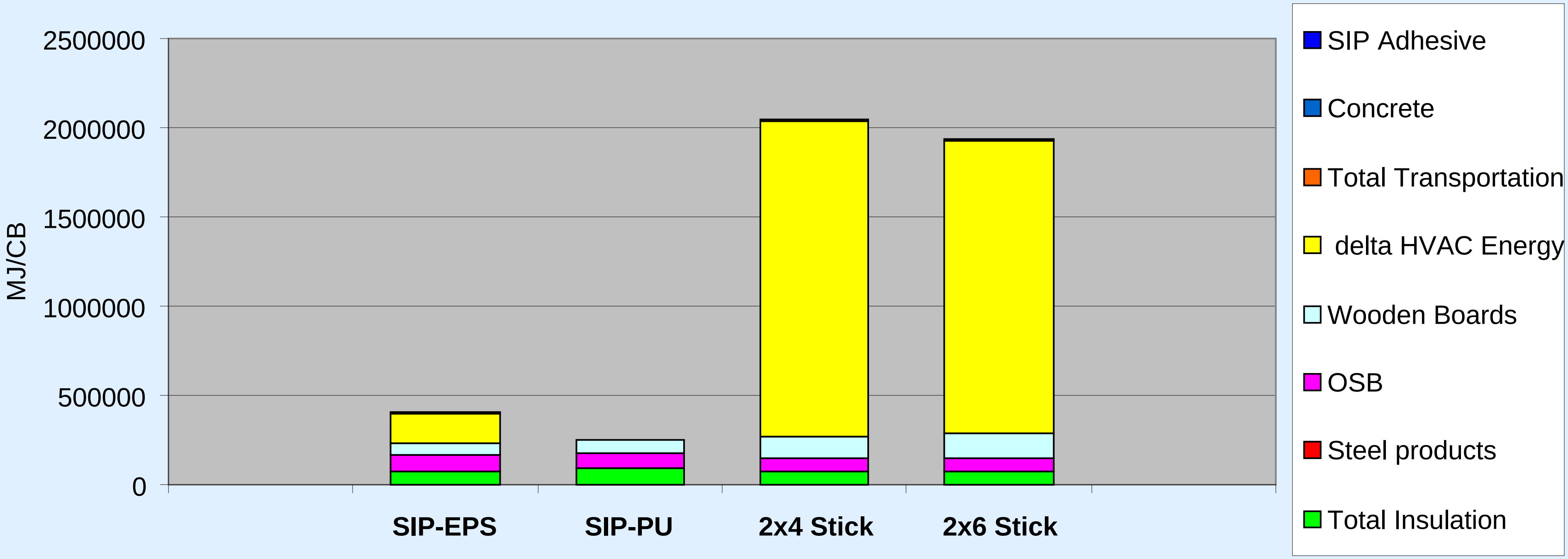

Heating and cooling (HVAC) energy consumption over the life of the home have much more impact than the production of the construction materials. HVAC energy is 70% for heating (natural gas) and 30% for cooling (electricity).

Comments regarding energy consumption

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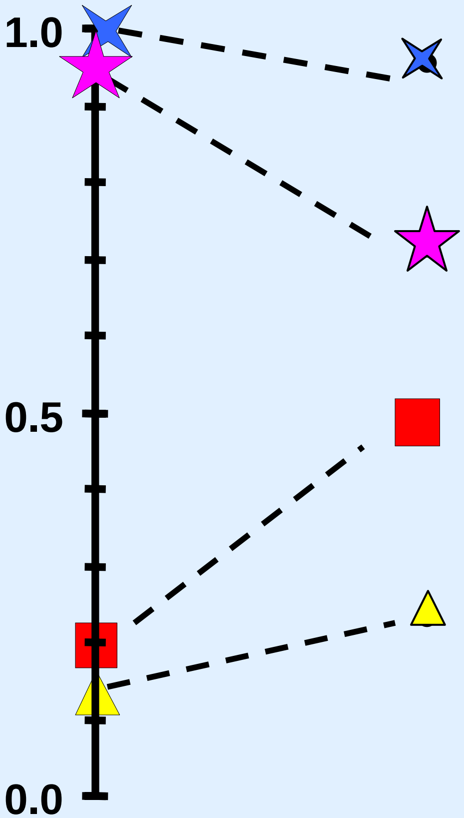

2x4 stick construction has the lowest R-value and significant air leakage resulting in the highest HVAC energy consumption over the lifetime of the home.

2x6 stick construction has a higher R-value than the 2x4 stick, but still has significant air leakage, contributing to high HVAC energy consumption.

EPS SIP has a slightly lower R-value than 2x6, but significantly lower air leakage and therefore uses less HVAC energy than stick construction.

PU SIP also has a high R-value and low air leakage thus leading to the most energy efficient alternative.

Resource consumption

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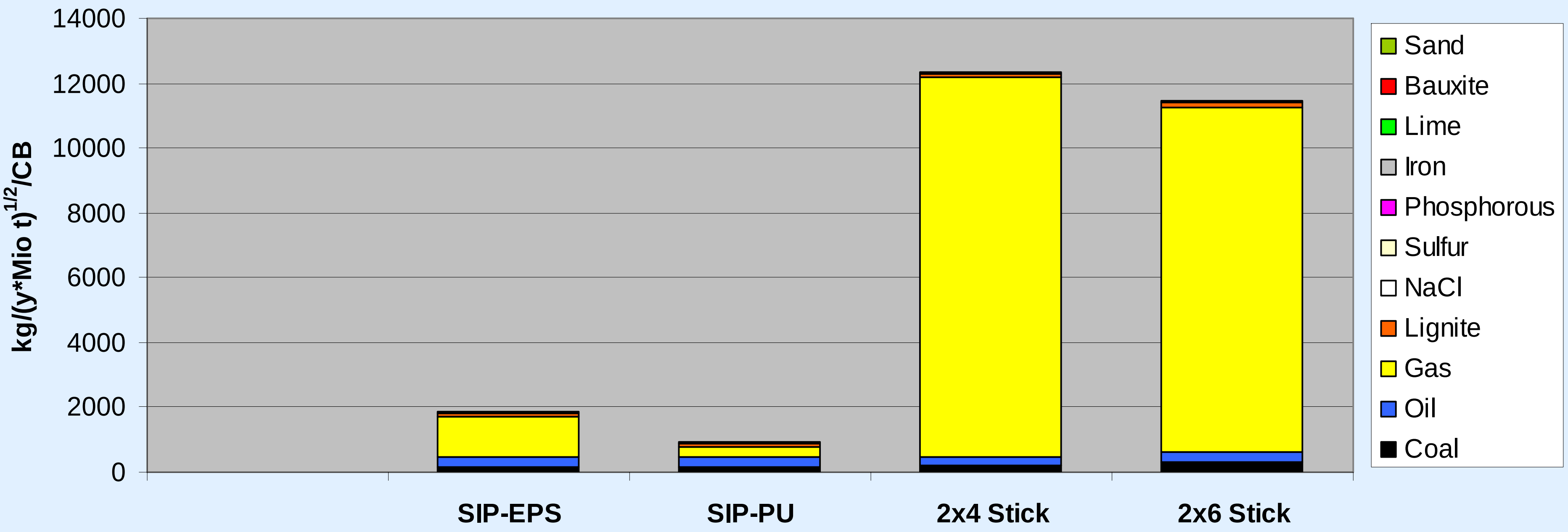

The largest consumption of resources is in natural gas, used as fuel for heating the home.

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Comments regarding resource consumption

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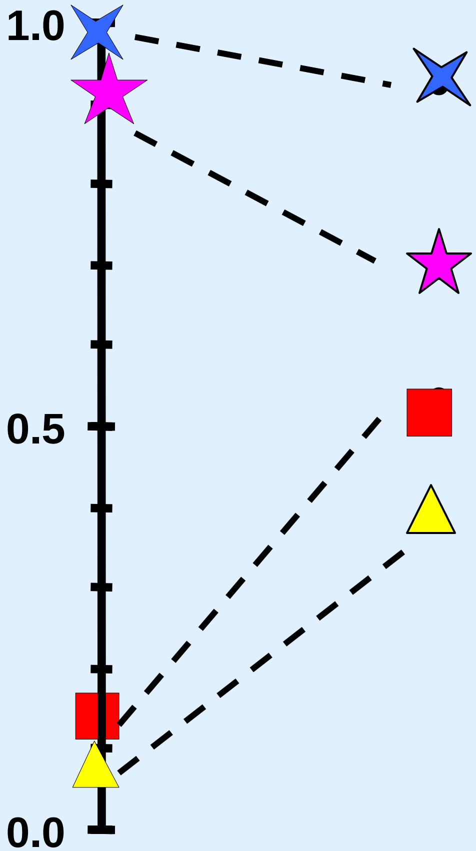

2x4 stick construction uses the most resources for heating and cooling of the home, due to it’s low R-value and high air leakage properties.

2x6 also uses large resource quantities because of its high air leakage rate and thus poorer energy efficiency.

EPS SIP uses significantly less resources as the other stick construction due to it’s better energy efficiency.

PU SIP uses the least amount of resources due to it’s high insulating value and low air leakage.

Global Warming Potential

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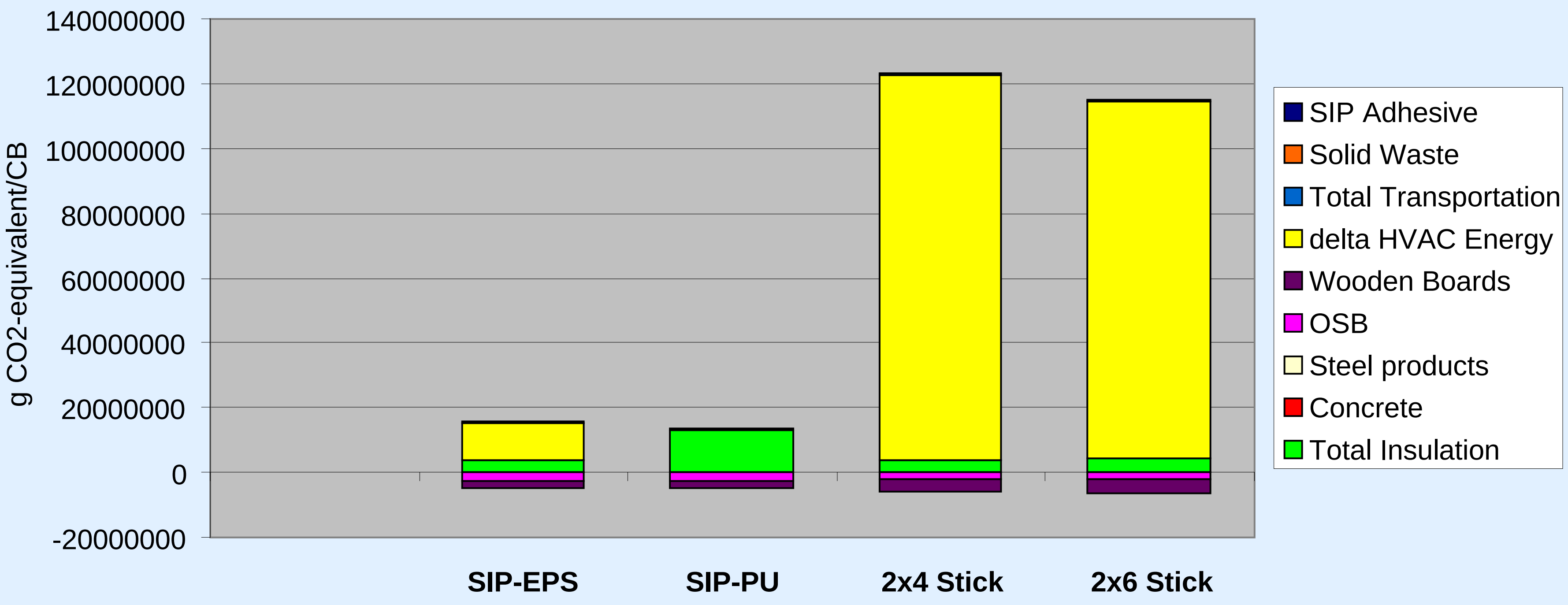

GWP is primarily a result of energy for heating and cooling the home over the lifetime. SIP PU greatest contributor is the blowing agents for the foam.

Photochemical Oxidant Creation Potential (Summer Smog)

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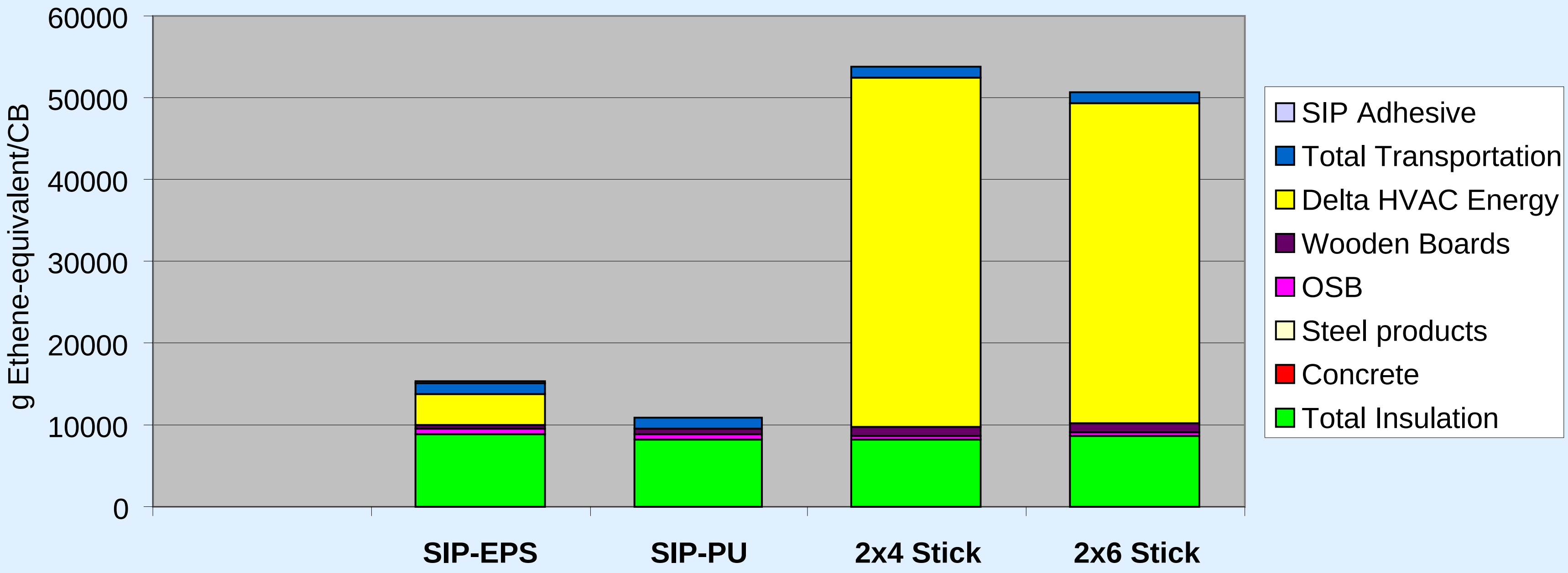

HVAC energy usage over the lifetime has the largest impact. Manufacture of the insulating materials also contributes, as well as transportation.

Acidification potential

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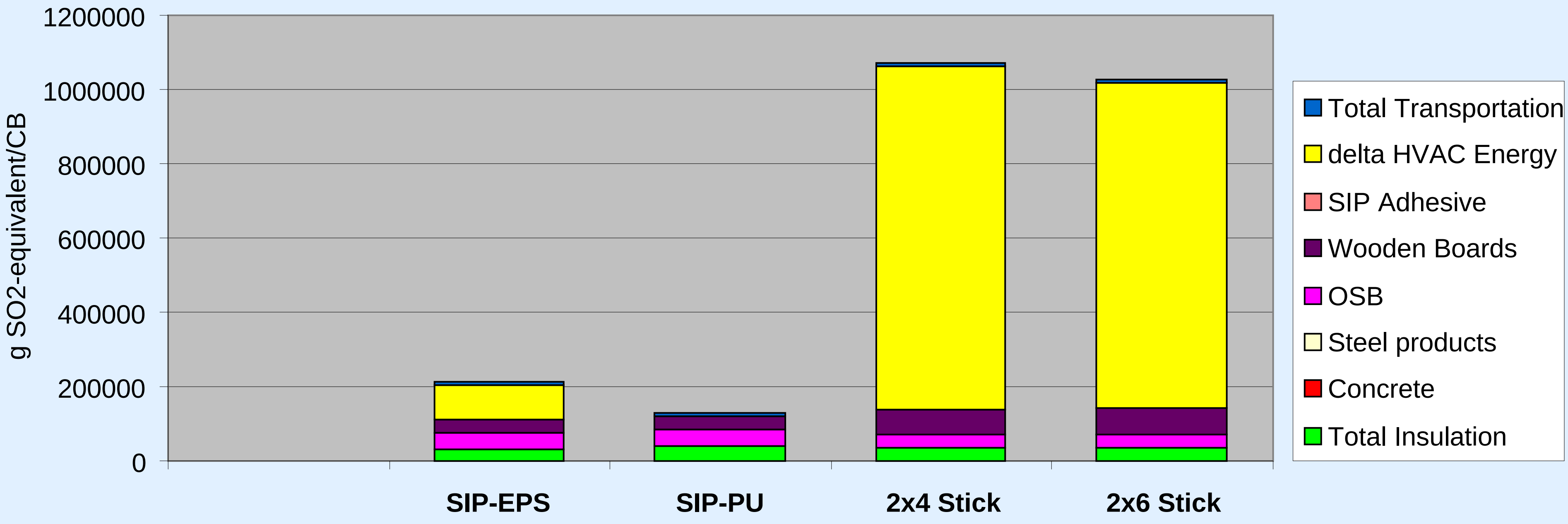

AP primarily results from NO_x, and SO_x generated due to energy use for heating and cooling of the home.

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Ozone Depletion Potential (ODP)

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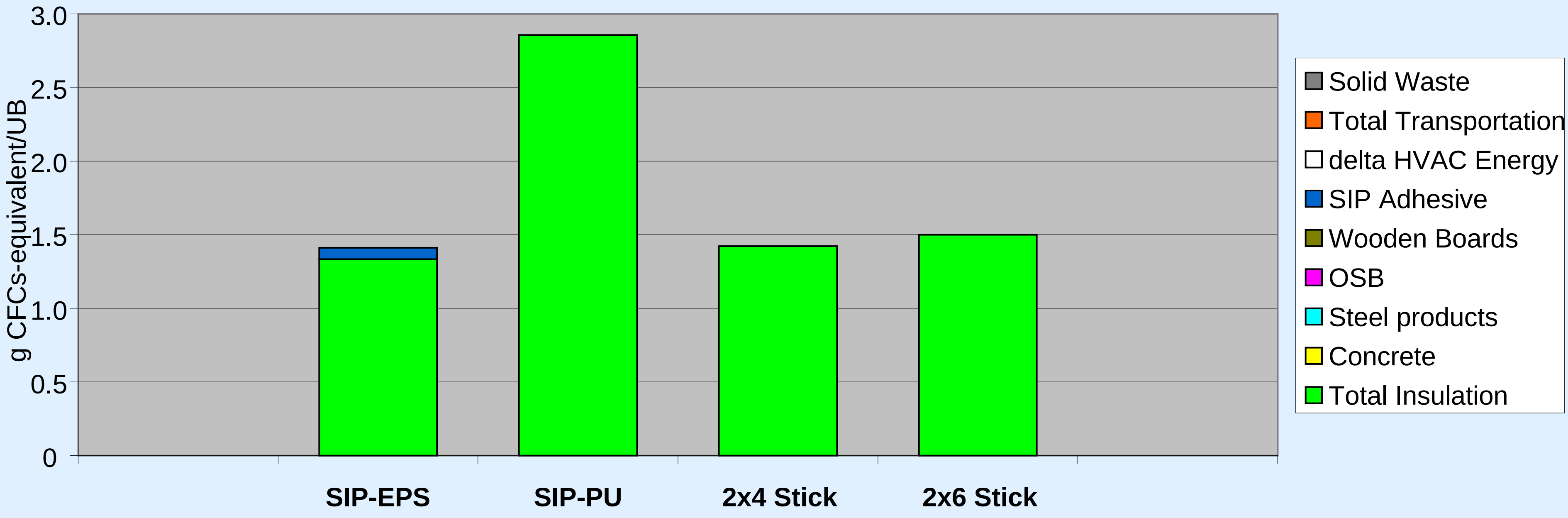

ODP mostly comes from the choice of insulation material.

Eco-Efficiency

Water emissions

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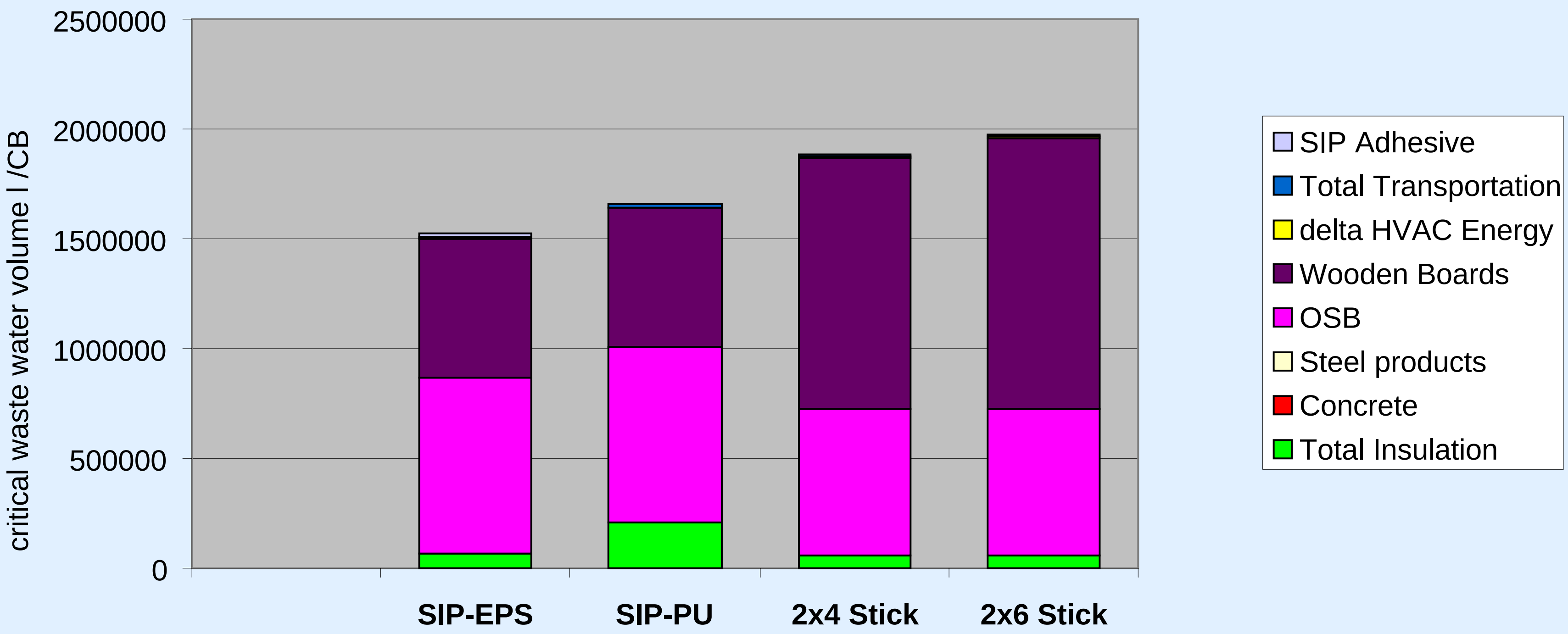

Water emissions are high due to the BOD and COD emissions from the wood production process, used for boards and OSB in the wall and roofing systems.

Solid Waste Emissions

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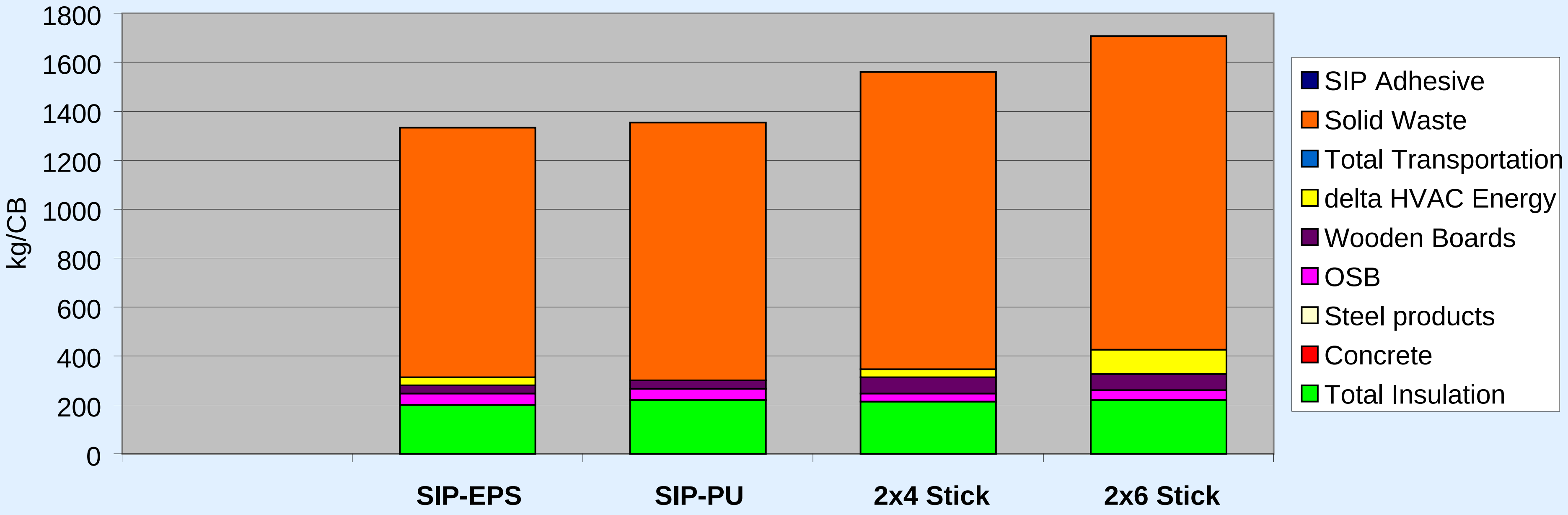

Solid waste emissions are primarily a result of construction materials sent to landfill. Thus the large mass of the stick construction techniques contribute to the largest solid waste emissions.

Comments regarding emissions

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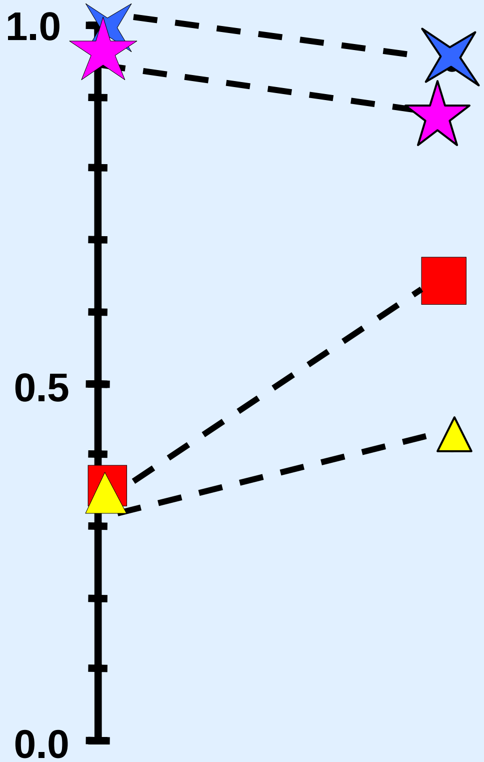

2x4 and 2x6 construction have the highest overall emissions, primarily because they have the highest air emissions due to the high energy consumption of the home over its lifetime. The wood production process also incurs high water emissions.

EPS SIP has low total emissions due to its high energy efficiency and light weight of system materials. It has the lowest impact on water emissions and solid waste emissions.

PU SIP has the lowest total emissions because of its high energy efficiency and thus reduction in air emissions due to the lowest energy requirement for heating and cooling the home over its lifetime.

Health Effect Potential - Production

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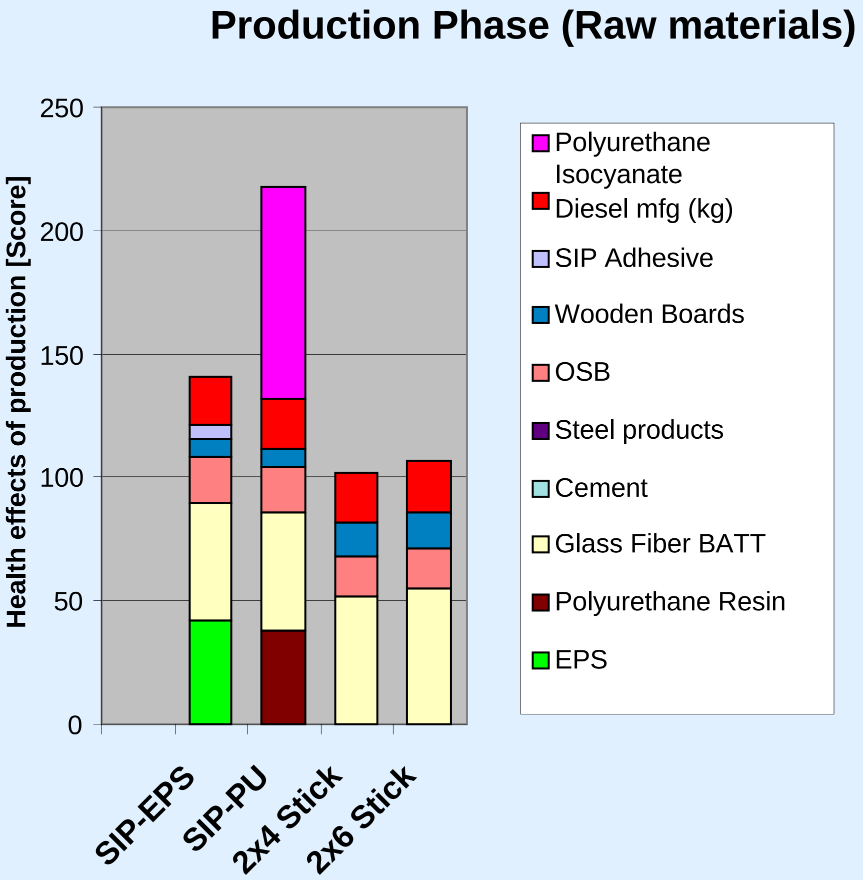

Highest Health impact is in the production (pre-chains) of the various insulation materials.

Eco-Efficiency

Health Effect Potential –Use

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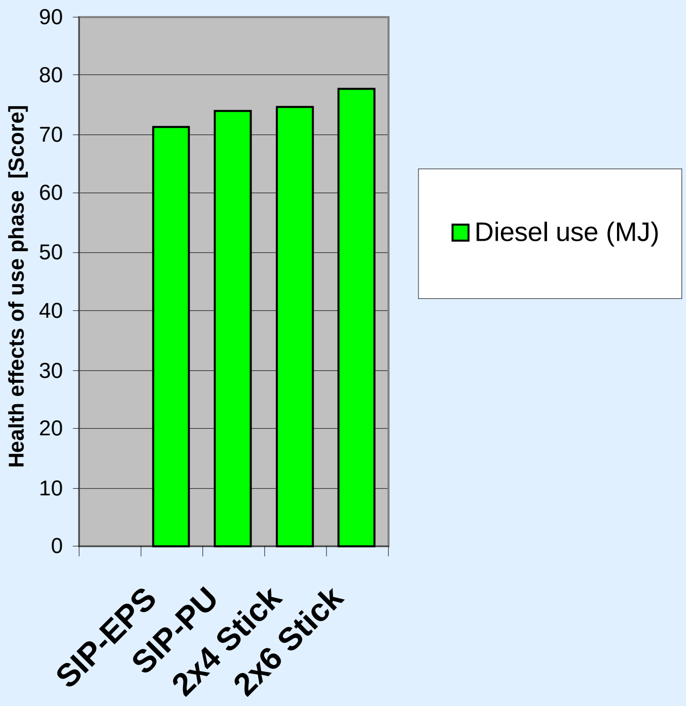
Use Phase



Diesel use for transportation of construction materials has the greatest impact during the use phase. Heavier systems use more fuel for transport, resulting in higher health effect potential.

Health Effect Potential – Disposal

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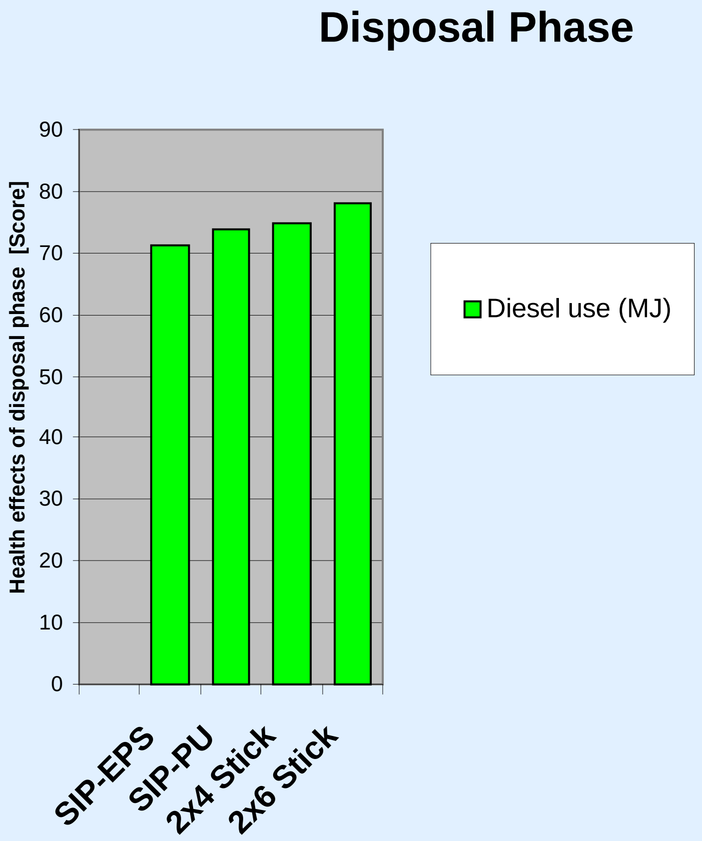

Diesel use for transportation of the construction materials after the home is demolished has the greatest impact on health effect potential during the disposal phase. Heavier systems use more fuel for transport, resulting in higher health effect potential.

Comments regarding potential health effects

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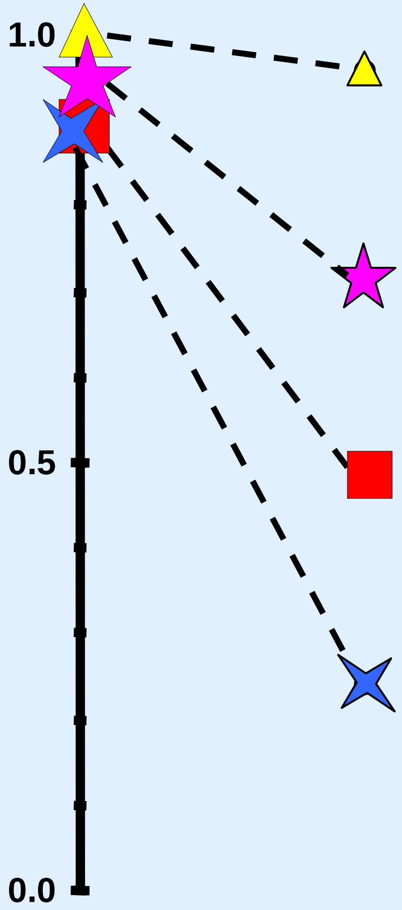

PU SIP has the highest health effect potential due to the contribution of the production of the raw materials required to make the foam.

The 2x6 system is the heaviest alternative and thus has a higher use of diesel fuel during the use and disposal phases.

EPS SIP is the lightest of all alternatives and uses the least amount of fuel during transport of materials during the use and disposal phases.

Though heavier than the two SIP alternatives, the 2x4 system benefits by having the lowest health effect potential in the production of raw materials.

Evaluation of the risk potential - Production

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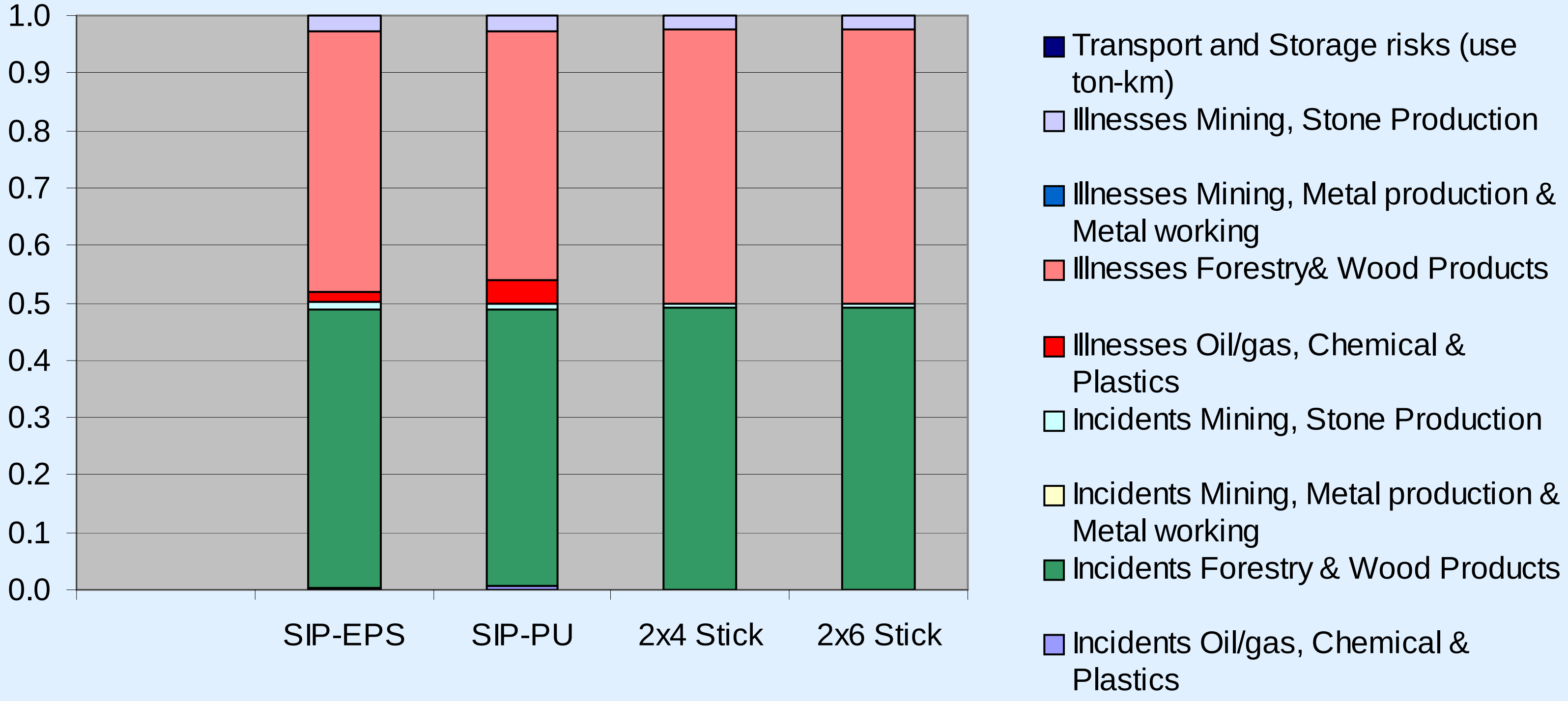

Risk potential during production uses industrial statistics for recordable incidents and occupational illnesses. The forestry and wood products industry has relatively high incident rates.

Evaluation of the risk potential - Use

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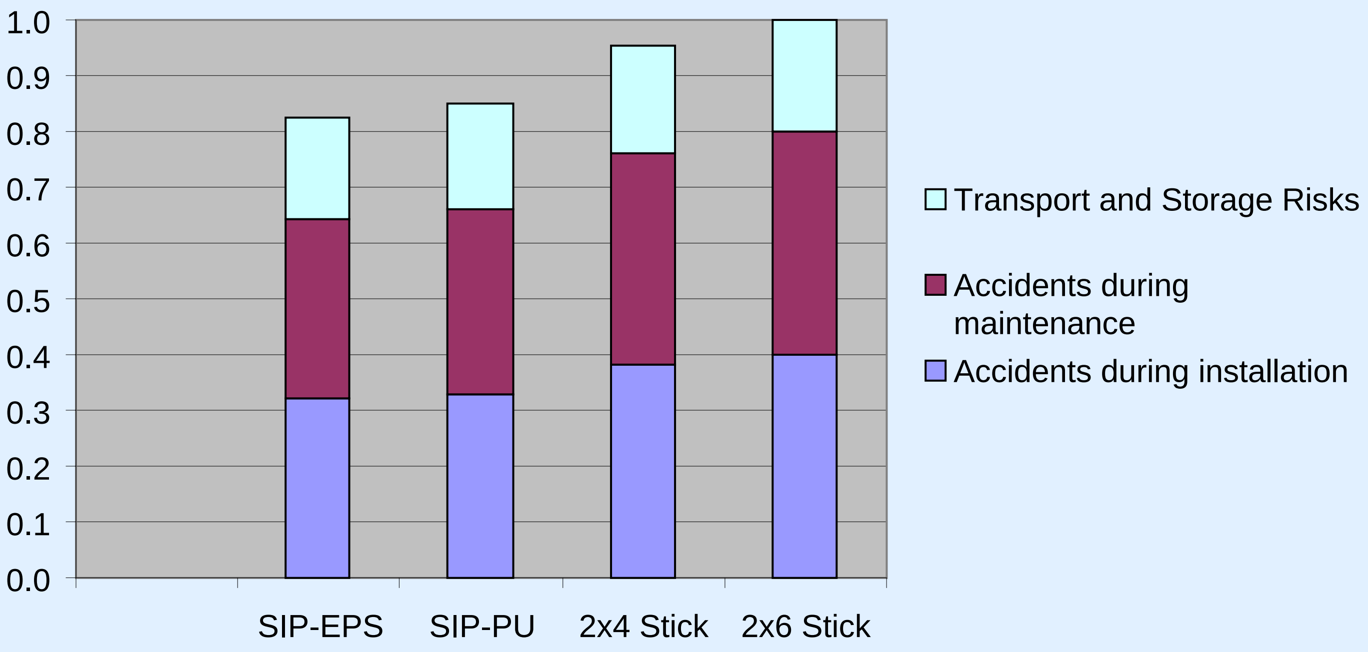

Installation procedures are different and the wood alternatives require more frequent maintenance and more materials. Transportation of system materials and their quantities also differentiate the alternatives.

Evaluation of the risk potential - Disposal

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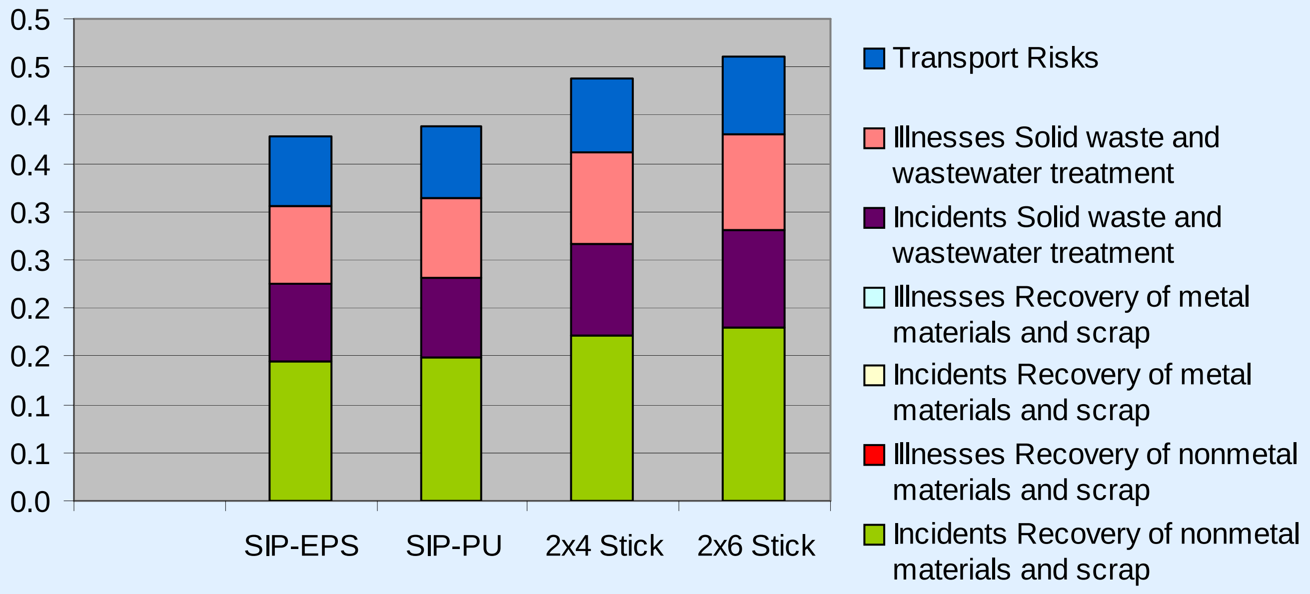

During disposal, systems that use the largest quantities of materials have the highest demolition risk associated with them.

Comments regarding risk potential

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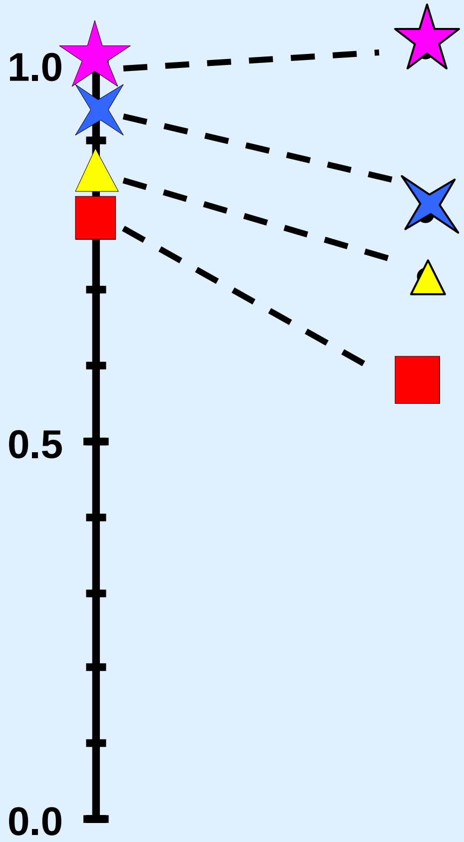

2x6 construction has higher risk due to the largest quantity of material produced and handled as well as more maintenance needed during the use phase.

2x4 construction uses a large quantity of material.

PU – SIP is a low maintenance system and uses less material than the stick build alternatives.

EPS - SIP uses the least material of all alternatives and is also a low-maintenance system. Least potential for risk during material transportation, storage and installation.

Evaluation of the Land Use

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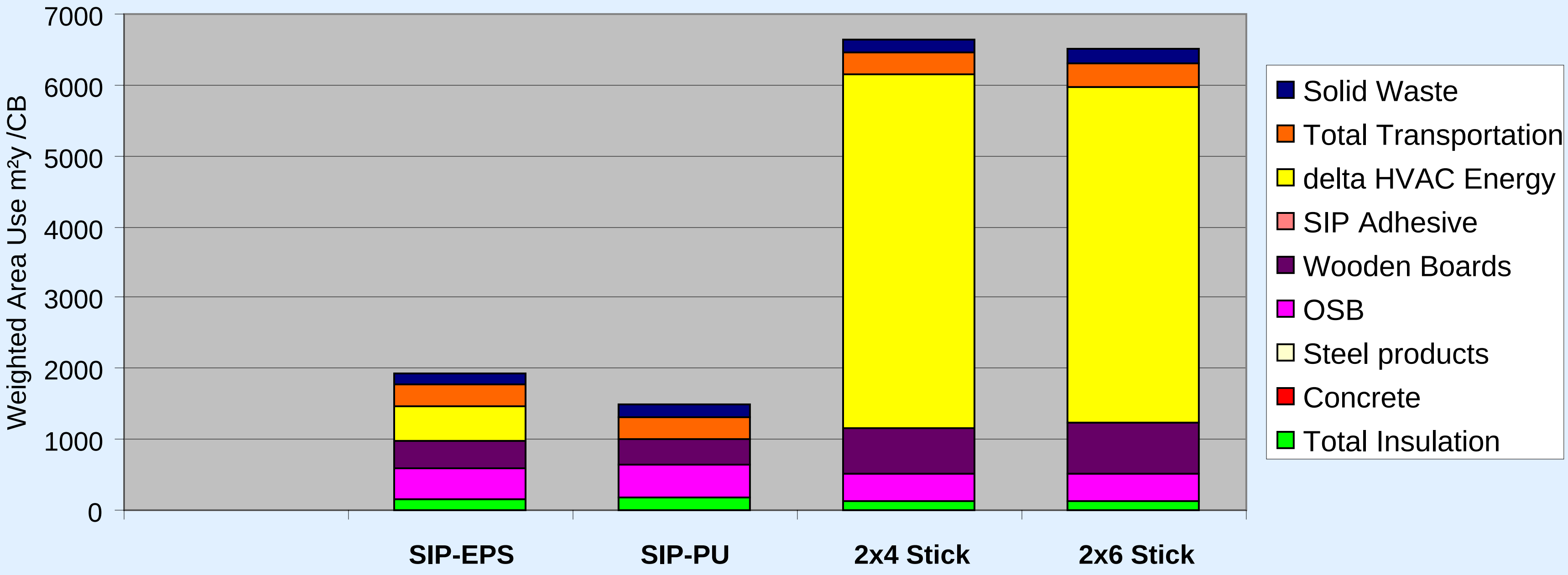

Land impacts of energy production used for heating and cooling the home are the largest. Production of wood products is also significant.

Comments regarding Land Use

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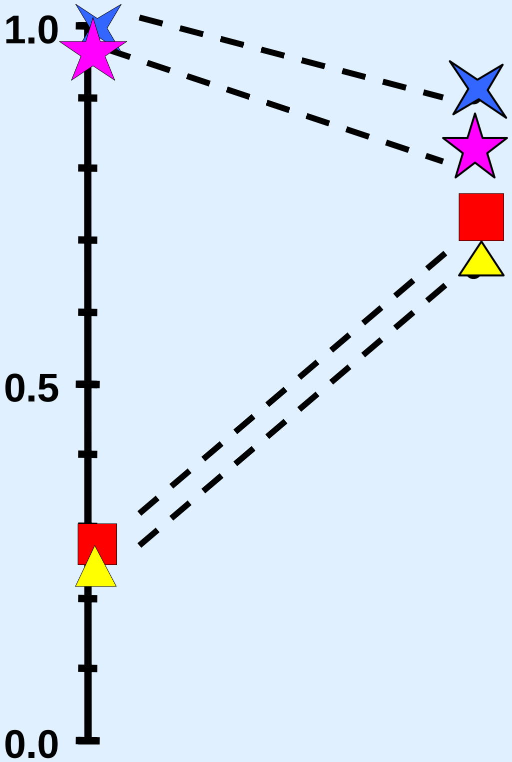

2x4 and 2x6 use the most energy for heating and cooling of the home and therefore have the greatest land use.

SIP construction use the least energy for heating and cooling of the home, and also the least diesel fuel for transportation, resulting in the lowest land use.

Scenarios

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Scenario 1: Energy and cost calculations are done for Tampa, Fla. (Zone 2)
Scenario 2: Energy and cost calculations are done for Las Vegas, Nevada. (Zone 3)
Scenario 3: Energy and cost calculations are done for Minneapolis, Minnesota. (Zone 6)

Scenario 1: Energy and cost calculations are done for Tampa Florida. (Zone 2)

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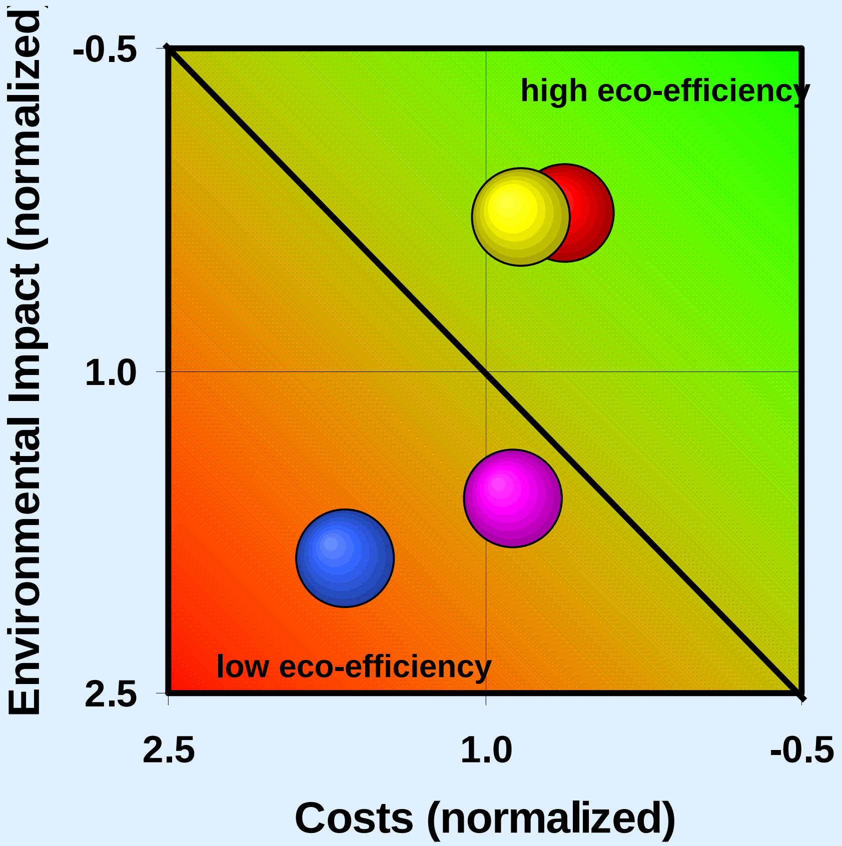
Customer Benefit (CB):

Construction, use & disposal of the walls and roof of a single story residential home in Tampa Fla., over 60 yrs.



- 🔴 SIP-EPS
- 🟡 SIP-PU
- 🔵 2x4 Stick
- 🟣 2x6 Stick

In this scenario EPS-SIP is the most eco-efficient.

Eco-Efficiency

Comments to Scenario 1

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- Lowest overall HVAC energy consumption for all alternatives (40-50% less than base case and 55-65% less than largest case, Minneapolis) and smallest difference in HVAC energy consumption between alternatives (<10%).
  - SIPs therefore do not enjoy as much benefit in all Environ Impact Areas.
  - Consumption switches from heating dominate zone to cooling dominate (70% electricity / 30% NG for HVAC vs. reverse for base case).
- With lower overall contribution to emissions from energy consumption, contribution of PU materials (specifically blowing agents and their contribution to GWP) increases PU SIP relative emissions score.
- Relevance - Calculation Factor observations (relative to base case):
  - Lower weighting on air emissions with increases in solid waste & water.
  - Higher relevance on AP vs. GWP but calculation factor favors GWP.
    - As climate warms, increased coal used in electricity generation
  - Much lower weighting on resource consumption
- With lowest overall (and energy) life cycle costs, initial installation costs have more significant impact (benefits stick construction; disadvantage to SIPs).
- Highest BIP-Relevance factor (2.65 vs. 1.53 base case). Life cycle costs decreasing proportionately faster than environmental impacts.

Scenario 2: Energy and cost calculations are done for Las Vegas, Nevada. (Zone 3)

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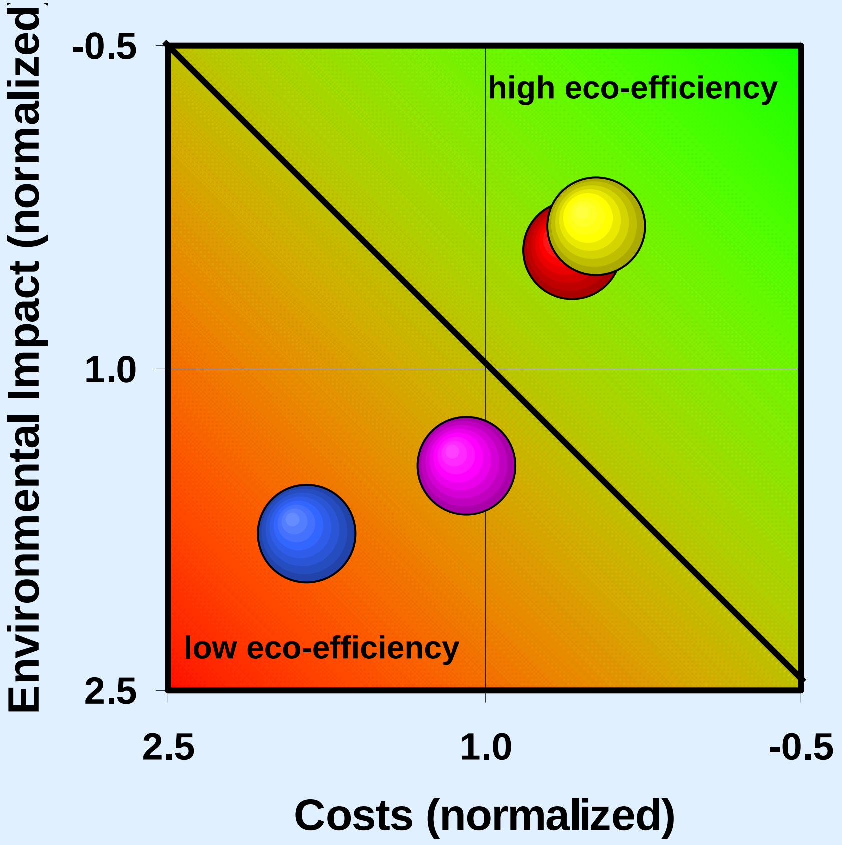
Customer Benefit (CB):

Construction, use & disposal of the walls and roof of a single story residential home in Las Vegas, Nevada, over 60 yrs..



- 🔴 SIP-EPS
- 🟡 SIP-PU
- 🔵 2x4 Stick
- 🟣 2x6 Stick

In this scenario, the PU-SIP alternative is the most eco-efficient.

Eco-Efficiency

Comments to Scenario 2

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- Lower overall HVAC energy consumption than base case. Difference in HVAC energy consumption between alternatives drops from ~ 35% to 15%.
  - SIPs therefore do not enjoy as much benefit in all Environ Impact Areas.
  - Consumption switches from heating dominate zone to cooling dominate (60% electricity / 40% NG for HVAC).
- With lowest overall (and energy) life cycle costs, initial installation costs have more significant impact (benefits stick construction; disadvantage to SIPs).
- BIP-Relevance factor of 1.9 (increase from base case of 1.53)

Scenario 3: Energy and cost calculations are done for Minneapolis, Minnesota. (Zone 6)

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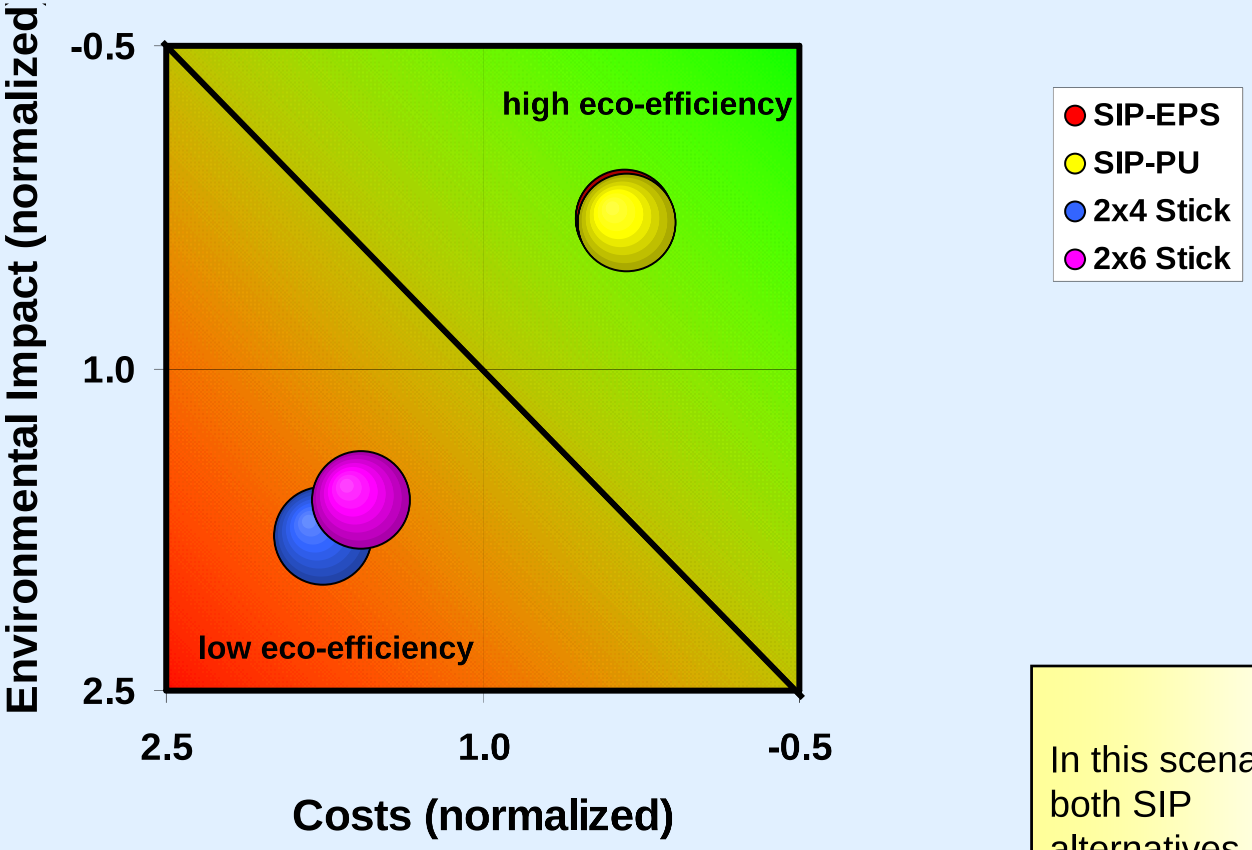
Customer Benefit (CB):

Construction, use & disposal of the walls and roof of a single story residential home in Minneapolis, Minnesota, over 60 yrs..



In this scenario both SIP alternatives have similar eco-efficiencies.

Eco-Efficiency

Comments to Scenario 3

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- Highest overall HVAC energy consumption for all alternatives (40-50% increase over base case) and largest difference in HVAC energy consumption between alternatives (~ 50%).
  - More energy efficient SIP designs benefit in all Environ Impact Areas.
  - Heating dominate zone (80% gas / 20% electricity) for HVAC.
- EPS SIPs required an additional 1“ of insulation (4.5“ total) in order to meet building code requirements (R-19).
- 2x4 Stick construction would not meet building code.
- Relevance - Calculation Factor observations (relative to base case):
  - Very similar calculation factors.
- With largest delta in overall (and energy) life cycle costs, initial installation costs have less significant impact (benefits SIP construction; disadvantage to stick construction).
  - Savings in life cycle energy consumption overcomes slight increase in initial cost for EPS SIP (going from 3.5“ to 4.5“ construction)
- Lowest BIP-Relevance factor (1.49 vs. 1.53 base case). Life cycle costs increasing slightly faster than environmental impacts.

Overall Scenario Observations

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Location Factor

Highest	Minneapolis	1.107
	Newark	1.106
	Las Vegas	1.034
Lowest	Tampa	0.913

Electricity ($/Kwhr)

Highest	Newark	0.1444
	Las Vegas	0.1182
	Tampa	0.112
Lowest	Minneapolis	0.0902

NG Fuel ($/therm)

Highest	Tampa	2.07
	Newark	1.43
	Las Vegas	1.39
Lowest	Minneapolis	1.092

Utilities Range (MJ/yr)

Highest	Minneapolis	104,000 – 150,400
	Newark	73,600 – 99,300
	Las Vegas	58,300 – 67,500
Lowest	Tampa	46,100 – 49,900

Utilities Range (K$/CB)

Highest	Minneapolis	61.9 – 81.5
	Newark	71.1 – 85.6
	Las Vegas	70.5 – 76.8
Lowest	Tampa	61.1 – 65.4

Overall Scenario Observations

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Life Cycle Cost (K$/CB)

Highest	Newark	112,000 – 123,000
	Minneapolis	103,000 – 121,000
	Las Vegas	115,000 – 119,000
Lowest	Tampa	96,500 – 98,000

Life Cycle Cost Delta (K$/CB)

Highest	Minneapolis	18,000
	Newark	11,000
	Las Vegas	4,000
Lowest	Tampa	1,500

Recommendations for residential insulation systems:

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- Marketing: Emphasize the life-cycle environmental and cost benefits of using high-efficiency insulating systems in residences. The SIP systems are the most eco-efficient because they provide high energy efficiency (low leakage rates and higher R-values), with low environmental impact of construction materials. However, in hotter climates, the higher installed costs of SIP systems coupled by the lower overall life cycle utility requirements, result in smaller eco-efficiency advantages between SIP construction and traditional stick construction.

  Though the highest initial installed cost, PU SIP overcomes this by having the highest energy efficient design and thus the lowest life cycle cost. This highly efficient design also allows for the lowest environmental burden.

Weighting and Relevance Factors
Base case (Newark, New Jersey)

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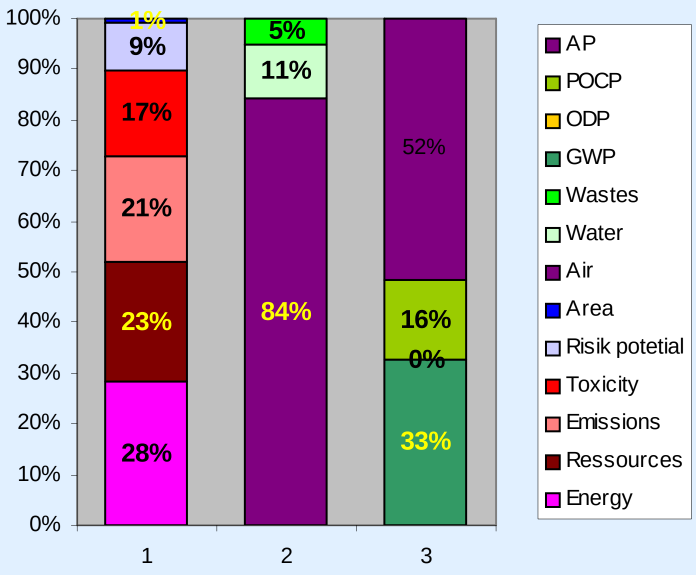
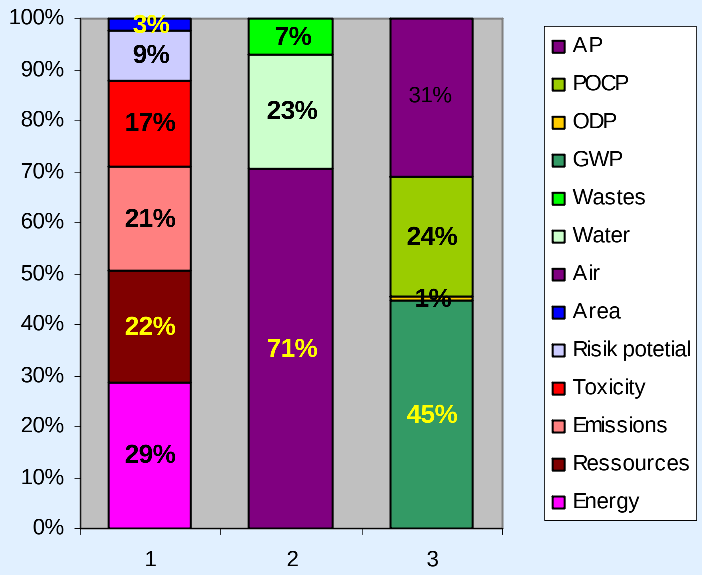
Relevance factors



Calculation factors



Energy consumption is the most significant environmental impact followed by raw materials consumption, emissions and health effect potential. Risk and Land Use are less significant. Air emissions are the most important emissions, followed by water and solid waste emissions. Global warming potential is the most important of the air emissions.

Appendix (A)
Data Sources

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Data for:	Source:	Year:	Quality:	Region:
System details and Energy Consumption, Estimated Leakage Area for conventional & tight systems, HVAC installation, maintenance and use costs	Energy10 v1.8.1082 from NREL, LBNL, SBIC, BSG, and DOE	Jun-06	High	U.S.A.
Regional Climate Data	Energy10 Weathermaker Typical Meteorlogical Year Data (TMY2)	Jun-06	High	U.S.A.
Regional Utility Pricing (Electricity & Natural Gas)	Energy Information Administration (US Government)	End 2007	High	U.S.A.
Building Code Requirements	2006 International Energy Conservation Code (IECC)	2006	High	U.S.A.
Home dimensions	Consistent with previous EPS SIPs study	2005	High	U.S.A.
Installation costs for 2x4 and 2x6 systems	RS Means with specific location factors	2006-2008	High	U.S.A.
EPS SIP material and installation costs	Insulspan	2008	Med-High	U.S.A.
PU SIP material and installation costs	Estimate based on EPS SIPS	2008	Med-Low	U.S.A.
Electricity, natural gas and diesel fuel eco-profiles	Boustead Database v. 5.0.12	1996	High	U.S.A.
Wood, OSB, steel, concrete, fiberglass BATT eco-profile data	Boustead Database v. 5.0.12	1996	High	U.S.A.
EPS production data	BASF internal information	2005	High	U.S.A.
SIP adhesive data	Rohm and Haas	2005	Medium	U.S.A.
Wood transportation distances	Wayne Trusty Athena Institute. Reference email 3/7/2006	2006	High	U.S.A.
PU Resin LCI Inventory	Various mfg. MSDS and technical data sheets	2008	Med-High	U.S.A.

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Contributions were made to this study by:

Chris Fennell @ BuildingInsight LLC

Appendix (B)
Methodology

The Eco-Efficiency Portfolio According to BASF

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Reference:
P. Saling, A. Kicherer et al, Int. J. LCA **7** (4), 203-218, (2002)

- BASF has developed the eco-efficiency portfolio to allow a clear illustration of eco-efficiency.
- The overall cost calculation and the calculation of the ecology fingerprint constitute independent calculations of the economic and environmental considerations of a complete system with different alternatives. Since ecology and economy are equally important in a sustainability study, a system can compensate for weaknesses in one area by good performance in the other. Alternatives whose sums of ecological and economic performance are equal are considered to be equally eco-efficient.
- The values obtained from the ecology fingerprint are multiplied by weighting factors (description of fingerprint and weighting factors can be found on subsequent pages) and added up in order to determine the environmental impact of each alternative. The various environmental impact values are normalized by the mean environmental impact and plotted on the eco-efficiency portfolio.

The Ecology Fingerprint According to BASF

- The impact categories are normalized (and, in the case of emissions and material consumption, also weighted) and plotted on the ecology fingerprint. This plot shows the ecological advantages and disadvantages of the alternatives relative to one another. The alternative with a value of one is the least favorable alternative in that category; the closer an alternative is to zero, the better its performance.
- The axes are independent of each other so that an alternative which is, for example, favorable in terms of energy consumption may be less favorable in terms of emissions.
- Using the ecology fingerprint, it is possible to find the areas in which improvements are necessary in order to optimize the whole system effectively.

Determination of Energy Consumption

The impact category energy consumption is based on the consumption of primary energy over the whole life cycle. The sum of fossil fuels before production and of the renewable energy before harvest or use is shown. Thus conversion losses from the generation of electricity and steam are taken into account. In the case of BASF processes, company-specific data is used. In the case of non-BASF processes, the UCPTE data set [1] is used. However, consideration of specific scenarios for the production of electricity and steam are possible, e.g. for site comparisons.

The energy consumption figures are assigned to the individual types of energy carriers. The consumption of the various forms of primary energy is taken into account in the consumption of raw materials.
In the category of “energy consumption”, there is no further conversion to specific impact categories. The energy consumption values are normalized so that the least favorable alternative assigned a value of 1; the other alternatives are arranged on an axis ranging from 0 to 1. The performance in all other environmental impact categories are compared in this manner.

In order to calculate the total energy requirement the lower calorific value of the primary energy equivalent is used. The following forms of energy are taken into account: coal, oil, gas, lignite, nuclear energy, hydraulic power, biomass and others.

[1] West European Electricity Coordination System
(UNION POUR LA COORDINATION DE LA PRODUCTION ET DU TRANSPORT DE L`ÉLÉCTRICITÉ)

Determination of Material Consumption

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The mass of raw materials necessary for each alternative is determined. The individual materials are then weighted according by a factor incorporating the life span and the fractional consumption of that material [2].

In the case of renewable raw materials, sustainable farming is assumed. Therefore, the resource that has been removed has been replenished in the period under consideration. This means an endless life span and thus a weighting factor of zero. Of course, in the case of renewable raw materials from non-sustainable farming (e.g. rainforest clearance), an appropriate (non-zero) weighting factor is used for the calculation.

High energy consumption can be correlated with low materials consumption if renewable raw materials such as wood or hydraulic power are used. What therefore appears to be double counting of raw material and energy consumption does not occur with these two categories.

[2] U.S. Geological Survey, Mineral Commodity Summaries, 1997; Römpp Chemie Lexikon, Thieme, Stuttgart; Institut für Weltwirtschaft, Kiel; D. Hargreaves et al, World Index of Resources and population, Dartmouth Publishing, 1994; World Resources, Guide to the Global Environment, Oxford 1996; Deutsches Institut für Wirtschaftsforschung, Berlin

Determination of Air Emissions

Air emissions of different gases are recorded separately and added up over the whole life cycle. In most processes, the emission of carbon dioxide is the largest air emission. This emission is typically followed (in terms of quantity) by emissions of sulfur and nitrogen oxides as well as N_2O and hydrocarbons. All emissions occurring during the life cycle are considered, for example for the generation and use of electricity as a source of energy. As a rule, these impact the manufacturing process through the consumption of sources of primary energy.

The effect of these air emissions in the environment varies depending on the type of gas. In order to take account of this, the various emission quantities are linked to scientifically determined assessment factors [3]. Using this method, the emissions of 21 kg of carbon dioxide have the same greenhouse effect as 1 kg of methane. These so-called impact categories are used for each emission. Some emissions, for example the emission of methane, play a role in several impact categories. The impact categories that are taken into consideration in the eco-efficiency analysis are the global warming potential, photochemical ozone creation potential (summer smog), acidification potential (acid rain) and ozone depletion potential.

[3] UBA Texts 23/95

Procedure for Assessing Water Emissions

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The assessment of water pollution is carried out by means of the “critical volume” model. For selected pollutants that enter the water, the theoretical water volume affected by the emission up to the statutory limit value (critical load) is determined. The volumes calculated for each pollutant are added up to yield the “critical volume”.

The factors for calculating the critical volume are shown in the table. The requirements that are made on sewage at the entry point into surface water, listed in the appendices to the German Waste Water Regulation (AbwV), are the basis for the factors.

These limit values are generally based on the relevance of the emitted substance for the environment; in some cases, technical issues were taken into account in establishing the statute. In spite of this restriction, BASF uses this method for several reasons:

- existence of complete database for most of the emissions
- recognition of the Waste Water Regulation and broad acceptance of the associated limit values

parameter	*Appendix to Waste Water Regulation (AbwV)*	requirement on waste water (mg/l)	factors for calculating ‚critical volumes’ (l/mg)
COD	*Nr. 1*	75	1/75
BOD$_5$	*Nr. 1*	15	1/15
N-total	*Nr. 1*	13	1/13
NH$_4$-N	*Nr. 1*	10	1/10
P-total	*Nr. 1*	1	1
AOX	*Nr. 9*	1	1
heavy metals	*Nr. 9*	∅ 1	1
HC	*Nr. 45*	2	½

COD: chemical oxygen demand; BOD$_5$: biochemical oxygen demand;. N-total: total nitrogen. NH$_4$-N: ammonium-nitrogen; P-total: total phosphorus; AOX: adsorbable organic halides; heavy metals: sum of copper, nickel, lead, mercury etc; HC: sum of hydrocarbons.

Determination of Solid Waste

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The results of the material balance on solid waste emissions are summarized into four waste categories: municipal waste, chemical (special) waste, construction waste and mining waste. Due to lack of other assessment criteria, the average costs (normalized) for the treatment or disposal of each type of waste are used as weighting factors to form the overall impact potential. Production residues that are incinerated are considered in the overall calculation by including the incineration energy and the emissions that occur during incineration.

Assessment of the Area Use

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Area is not consumed like a raw material but, depending on the type, scope and intensity of the use, is changed so radically that it is impaired or even destroyed in its ability to perform tits natural function. Apart from the direct loss of fertile soil, there are a series of subsequent effects, for example cutting into ecosystems, loss of living space for flora and fauna, etc.

Area necessary to fulfill the customer benefit is considered for each alternative. The area requirement is assessed by weighting according to principal type of use and in relation to the relevance of the area requirement. Since virtually all the countryside in Europe is cultivated, the origins of the areas are not important. For special questions (e.g. conversion of rainforest to plantations), there is no difficulty in extending the consideration of the area requirement in this direction.

The life cycle consists of construction, operation and demolition and is put in relation to the overall capacity of the system. In the case of non-renewable resources, the recultivation time is taken into account.

	area type		assessment factor
0	natural	unaffected ecosystems	0
I	close to nature	forestry use, forest areas and bio-agriculture close to nature	1
II	semi-natural	semi-natural agricultural use, green area	1.5
III	remote from nature	agricultural use and arable cropping remote from nature	2.3
IV	sealed	sealed and impaired area, industrial area	5.1
	sealed & separating	traffic areas that split up ecosystems (roads, railwys and waterways)	7.6

Assessment of the Area Use: Examples

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	amount	area II	area III	area IV	area V
materials		m2a	m2a	m2a	m2a
platinum post-enrichment	100 kg	-24990.00	21680.00	2647.42	665.28
aluminum 0% recycled	100 kg	-49.59	45.39	3.43	0.91
polypropylene	100 kg	-20.56	18.63	1.84	0.09
cement	100 kg	-0.84	0.69	0.09	0.07
energy					
unleaded gasoline post-refinery	t	-97.77	86.05	11.26	0.48
electricity- West Germany mix	GJ	-9667.00	9374.00	260.77	32.45

	alternative 1			alternative 2		
	numerical value	factor	numerical value	numerical value	factor	numerical value
area II	4	1.5	6	2	1.5	3
area III	10	2.3	23	5	2.3	11.5
area IV	0.6	5.1	3.1	0.6	5.1	3.1
area V	0.1	7.6	0.8	1.2	7.6	9.1
sum			32.9			26.7

The numerical values are weighted and added up.
Then the normalization is carried out as well as the determination of the relevance.

Determination of the Overall Environmental Impact

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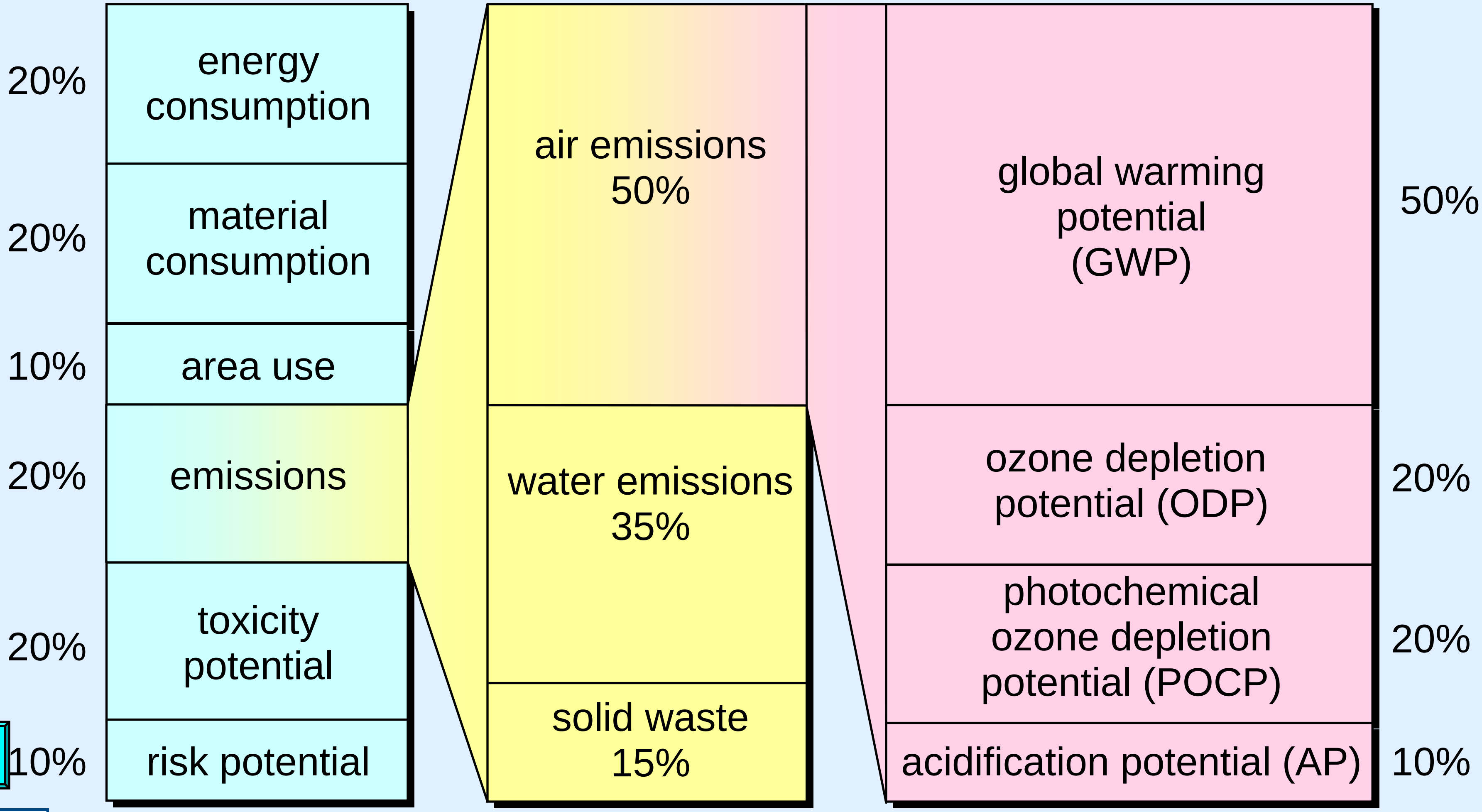
The values obtained in the material balance and impact estimate (greenhouse potential, ozone depletion potential, photochemical ozone formation potential, acidification potential, water emissions, solid waste, energy consumption, raw material consumption and area requirement) are aggregated with weighting factors to yield an overall environmental impact value. The weighting factors consist of the following:

- a *societal factor:*
  What value does society attach to the reduction of the individual potentials?
- a r*elevance factor*:
  What is the fractional contribution of the specific emission (or consumption) to the overall countrywide emissions?

Determination of Environmental Impact: Societal Weighting Factors



20% energy consumption

20% material consumption

10% area use

20% emissions

- air emissions 50%
    - global warming potential (GWP) 50%
    - ozone depletion potential (ODP) 20%
    - photochemical ozone depletion potential (POCP) 20%
    - acidification potential (AP) 10%
- water emissions 35%
- solid waste 15%

20% toxicity potential

10% risk potential

Relevance Factors

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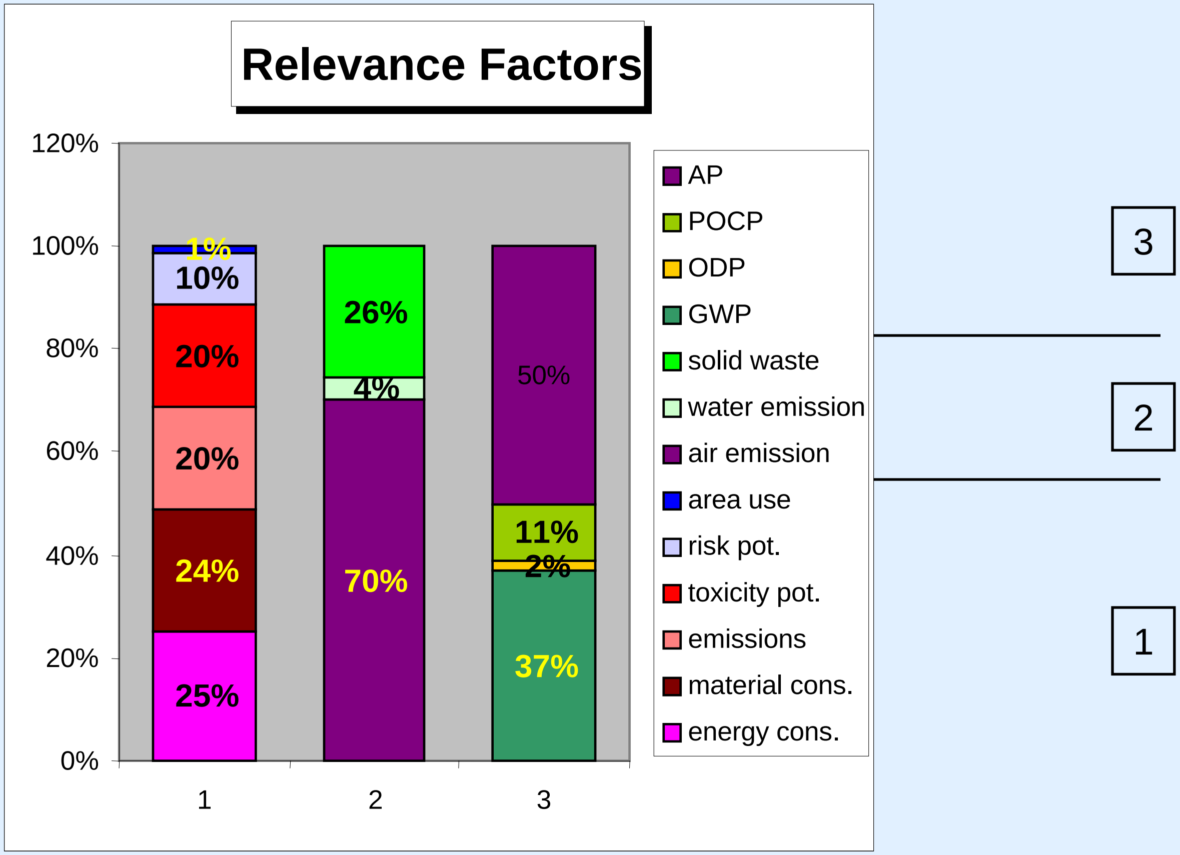

Weighting Factors

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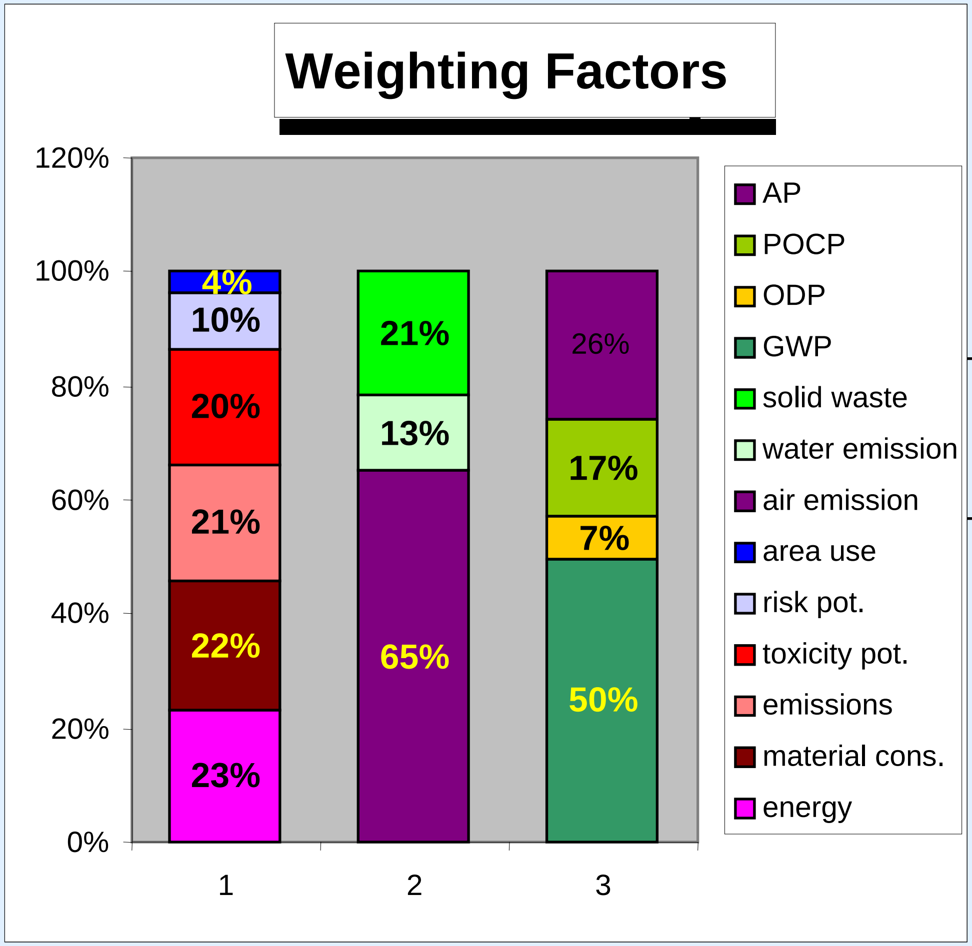

3

2

1

Weighting factors are derived from relevance factors and societal factors.

Determination of the Toxicity Potential

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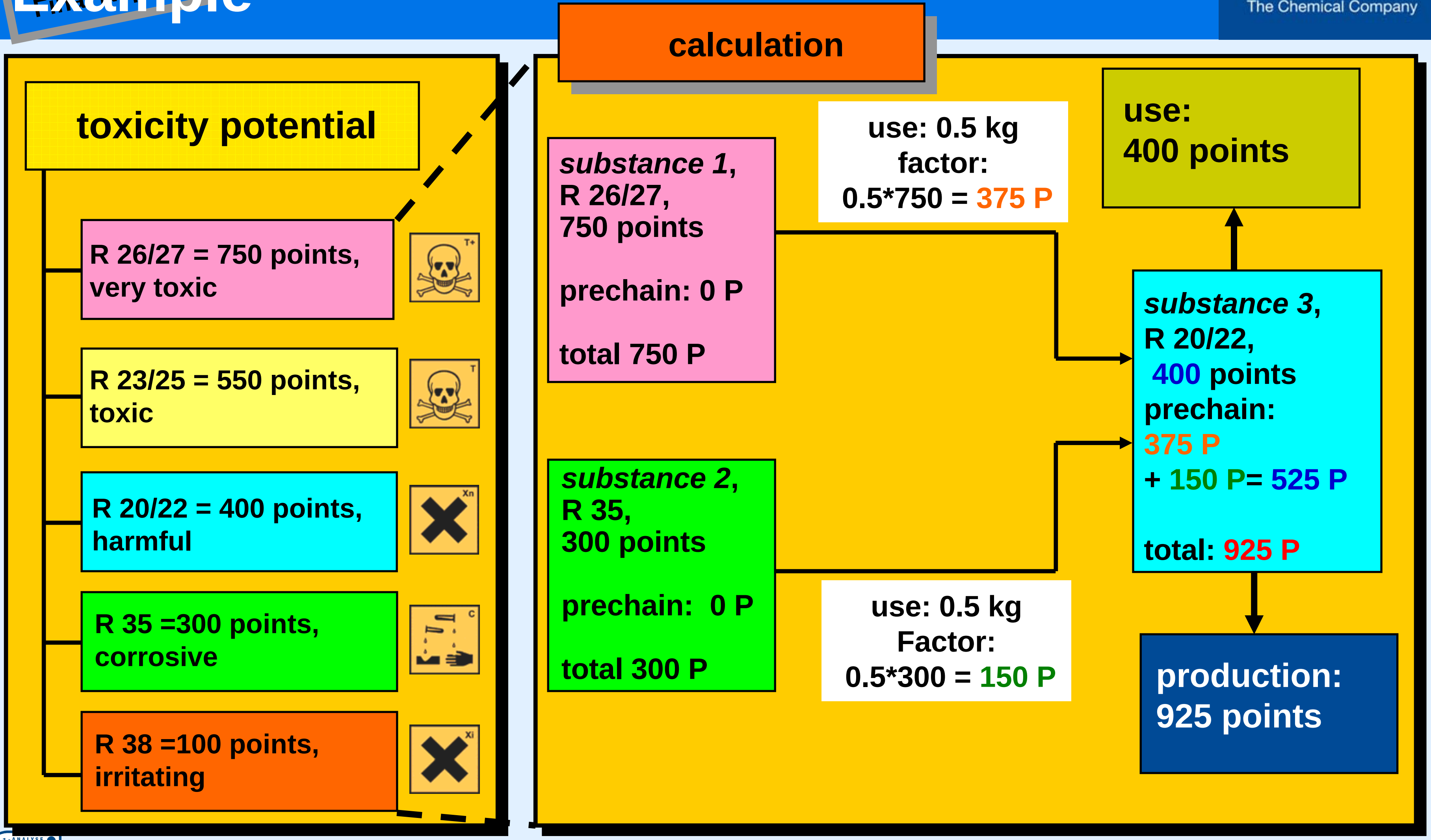
Reference: R. Landsiedel, P. Saling, Int. J. LCA **7** (5), 261-268, (2002)

- The toxicity potential is determined using an assessment method developed by BASF based on the R-phrases of the Hazardous Substances Regulation Act (GefStoffV). In cooperation with toxicologists numerical values ranging between 0 and 1000 were assigned to each R-phrase (or combinations thereof) according to their risk potential. For example, the classification R 26/27 (very toxic) is worth 750 points and the considerably less critical category R 35 (corrosive), 300 points (see example on next page). These R-phrase-based values are determined for all intermediate and final products that are used during the life cycle of each alternative, taking into account likelihood of human exposure.
- The calculated index figures are multiplied by the amounts of substances used and and added up to yield the overall toxicity potential over the life cycle.
- In the production category, only the actual R-phrases of a substance are considered. In contrast, in the production phase, the R-phrases of the pre-chain are evaluated as well as of the substance being produced.
- The results of these assessments are expressed in dimensionless toxicity units which can be compared with one another by normalizing and weighting the various life span phases.
- Only potential toxicity values are calculated. In order to be able to assess an actual risk to humans, additional calculations on the exposure of humans, uptake of the substance, etc., are needed.

Determination of the Toxicity Potential: Example



toxicity potential

R 26/27 = 750 points, very toxic

R 23/25 = 550 points, toxic

R 20/22 = 400 points, harmful

R 35 =300 points, corrosive

R 38 =100 points, irritating

calculation

substance 1, R 26/27, 750 points

prechain: 0 P

total 750 P

use: 0.5 kg
factor:
0.5*750 = 375 P

substance 2, R 35, 300 points

prechain: 0 P

total 300 P

use: 0.5 kg
Factor:
0.5*300 = 150 P

substance 3, R 20/22, 400 points
prechain:
375 P
+ 150 P= 525 P

total: 925 P

use:
400 points

production:
925 points

Determination of the Risk Potential

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- The risk potential in the eco-efficiency analysis is established using expert judgement. The focus is always on the severity of potential damage that an operation can cause, multiplied by its probability.
- In the risk potential category, different types the damage can be considered. For example, possible damage due to physical reactions (explosion or fire hazards and transportation risks), impurities in the product, incorrect handling, incorrect storage, etc may be included.
- The criteria of the risk potential are variable and may be different in each study, because they are adapted to the circumstances and special features of the particular alternatives. The number of risk categories may vary.
- Data on accidents in various industries or in various occupations may be included, for example safety data on various types of reactions in the chemical industry.
- All aspects of the complete life cycle are included in the assessment.
- Risk potentials are calculated values. In order to be able to estimate a risk actually occurring to a human, additional calculations and estimates are required.

Glossary

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Glossary of Abbreviations and Technical Terms I

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AOX: abbr. for absorbable organic halogen, a category of water emissions

AP: abbr. for acidification potential or acid rain. In this impact category, the effects of air emissions that lower the local pH values of soils and can thus e.g. cause forest death are taken into account.

BOD: abbr. for biological oxygen demand. This is a method for determining wastewater loads.

CB: abbr. for customer benefit. All impacts (costs, environment) are specific to this customer benefit which all alternatives being evaluated have to fulfill.

CH_4: abbr. for methane.

Cl^-: abbr. for chloride.

COD: abbr. for chemical oxygen demand. This is a method for determining wastewater. loads.

CO_2: abbr. for carbon dioxide.

critical volume: operand for assessing the extent to which wastewater is polluted by mathematically diluting the wastewater with fresh water until the allowed limit value is reached. This volume of fresh water that has been added is referred to as the critical volume.

municipal waste: waste that may be deposited on a normal household landfill.

emissions: emissions are categorized as emissions into air, water and soil. These broad groupings are further subdivided into more specific categories.

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Glossary of Abbreviations and Technical Terms II

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energy unit: energy is expressed in megajoules (MJ). 1 **MJ** is equivalent to 3.6 kilowatt hours (**kWh**).

feedstock: the energy content that is bound in the materials used and can be used e.g. in incineration processes.

GWP: abbr. for global warming potential, the greenhouse effect. This impact category takes into account the effects of air emissions that lead to global warming of the earth’s surface.

hal. HC: abbr. for halogenated hydrocarbons.

halogenated NM VOC: abbr. for halogenated non-methane volatile hydrocarbons.

HC: abbr. for various hydrocarbons or hydrocarbon emissions into water.

HCl: abbr. for hydrogen chloride.

HM: abbr. for heavy metals.

impact potential: name of an operand that mathematically takes into account the impact of an emission on a defined compartment of the environment.

material consumption: in this category, the consumption of raw materials is considered along with worldwide consumption and remaining reserves. Thus, a raw material with smaller reserves or greater worlwide consumption rates is more critically weighted.

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Glossary of Abbreviations and Technical Terms III

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NH_3: abbr. for ammonia emissions.

NH_4^+: abbr. for emissions of ammonium into water.

NM VOC: abbr. for non-methane volatile organic compound.

N_2O: abbr. for N_2O emissions.

NO_x: abbr. for various nitrogen oxides.

normalization: in the eco-efficiency analysis, the worst performance in each ecological category is normalized to a value of one. Thus alternatives with better performance in that category will lie between zero and one on the ecological fingerprint.

ODP: abbr. for ozone depletion potential, damage to the ozone layer. This impact category takes into account the effects of air emissions that lead to the destruction of the ozone layer of the upper layers of air and thus to an increase in UV radiation.

PO_4^{3-}: abbr. for emissions of phosphate into water.

POCP: abbr. for photochemical ozone creation potential. This effect category takes into account the effects of local emissions that lead to an increase in ozone close to the ground and thus contribute to what is known as summer smog.

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Glossary of Abbreviations and Technical Terms IV

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risk potential: impact category assessing the effects of risk factors over the complete life cycle. Risks such as transportation risks, dangers of explosion, dangers of accidents, etc. may be included

SO_x: abbr. for various sulfur dioxides.

SO_4^{2-}: abbr. for emissions of sulfates into water.

special waste: waste that has to be deposited on a special landfill.

system boundary: determines what aspects are considered in the study.

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Glossary of abbreviations & technical terms used V

Time span: The period for which a raw material is still available and can be used. The current use of the raw material in relation to what is currently known to be the amount that is still available and can be used industrially is the basis for the assessment.

Total N: Collective term for all water pollutants that contain nitrogen and that cannot be included in one of the other categories.

Toxicity potential: In this category, the effect of the substances involved is assessed with regard to their effect on human health. It relates solely to possible material effects in the whole life span. Further data have to be used to assess a direct risk.

The symbols have the following meanings: T+: very toxic; T: toxic; Xn: harmful; C: corrosive; Xi: irritating.