Buildings are not risk-free – balancing sustainability with fire and health effects

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Risks from exposure to a fire

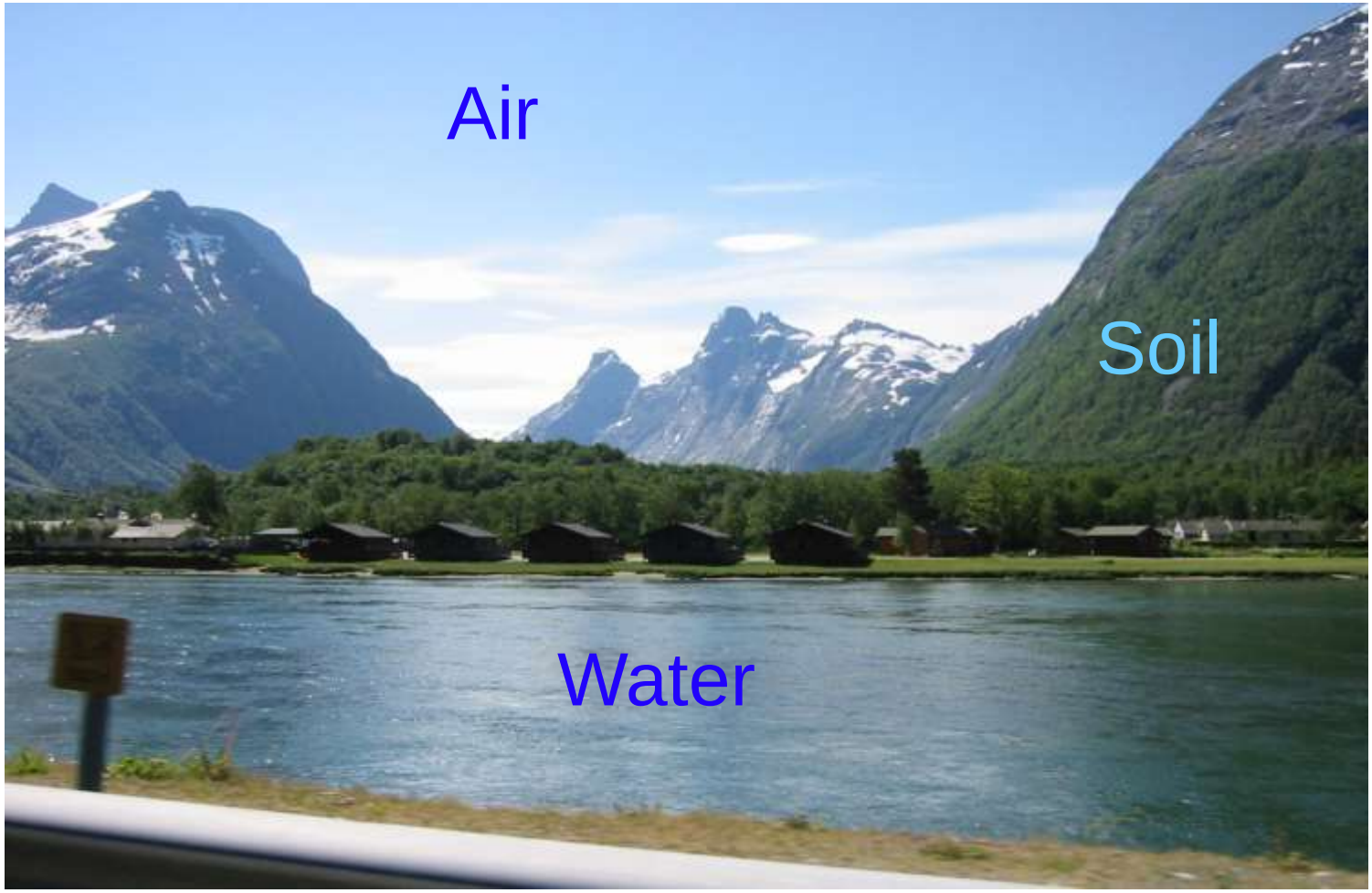
In the immediate vicinity:

- Acute toxic gases
- Smoke/particles
- Heat

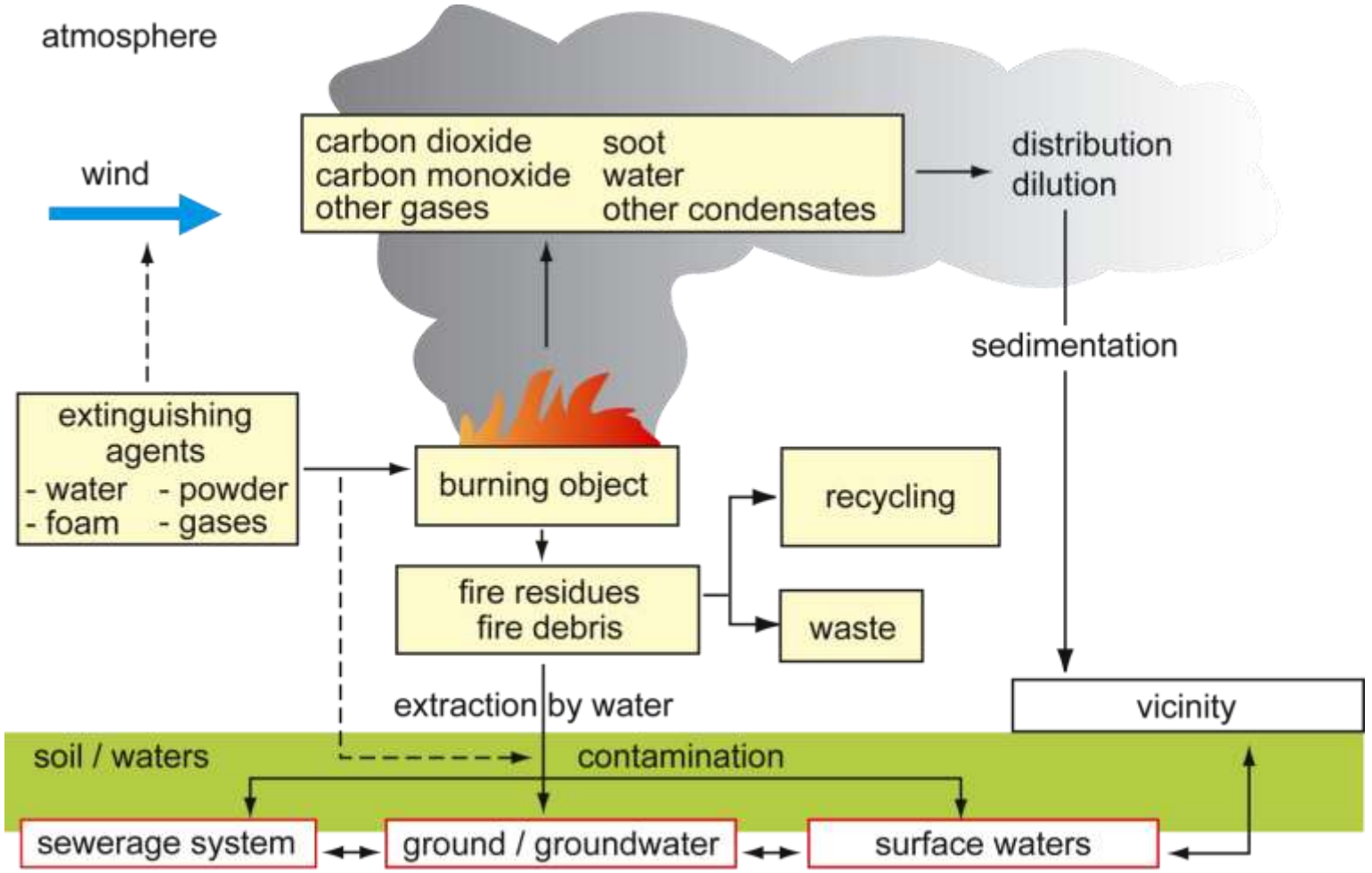
Further afield:

- Acute toxic gases
- POPs, PBTs
- Groundwater contamination
- Soil contamination

Emission Pathways (1/2)



Emission Pathways (2/2)



(ISO 26367-1, 2)

Toxic/Eco-toxic Effect

Effect	Type of emission
Acute toxicity	CO, HCN, acid gases, NO_x
Long term toxicity	Dioxins, PAH, POPs, particles, metals
Acidifying	Acid gases, NO_x, SO_x
Global warming	CO_2, CH_4, N_2O
Ozone depletion	NO_x, VOC

NB: The impact of an emission is dependent both on the type of emission and the sensitivity of the recipient

Fire Emissions

Combustion (optimised):

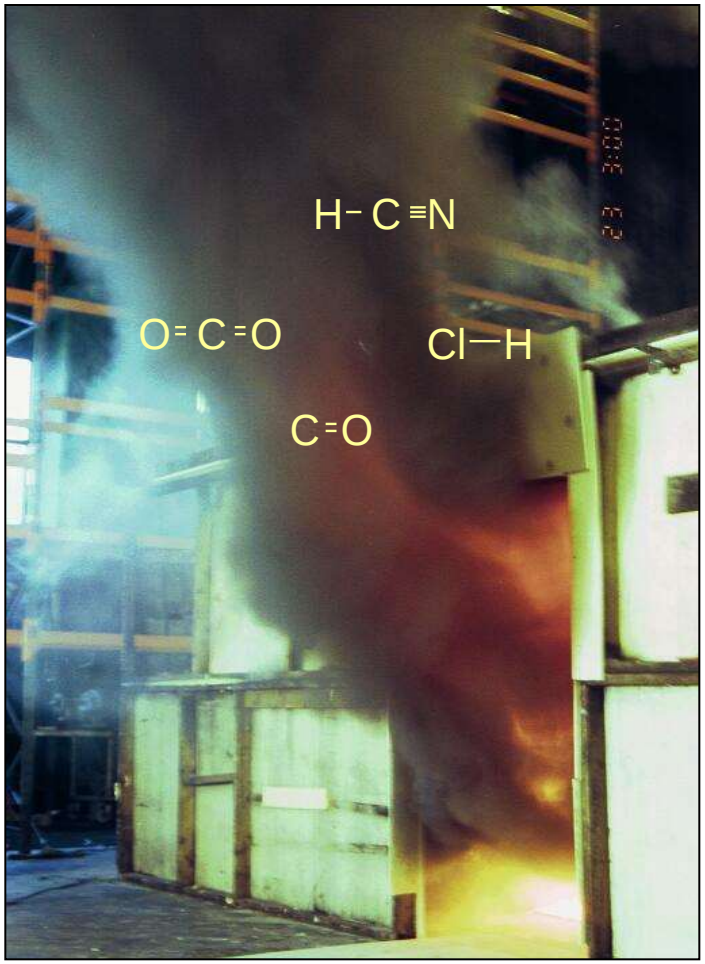
$$\text{Fuel} + O_2 \Longrightarrow CO_2 + H_2O$$

Fire:

$$\text{Fuel} + O_2 \Longrightarrow$$

$CO_2 + H_2O + CO$ + particles + 100s species…

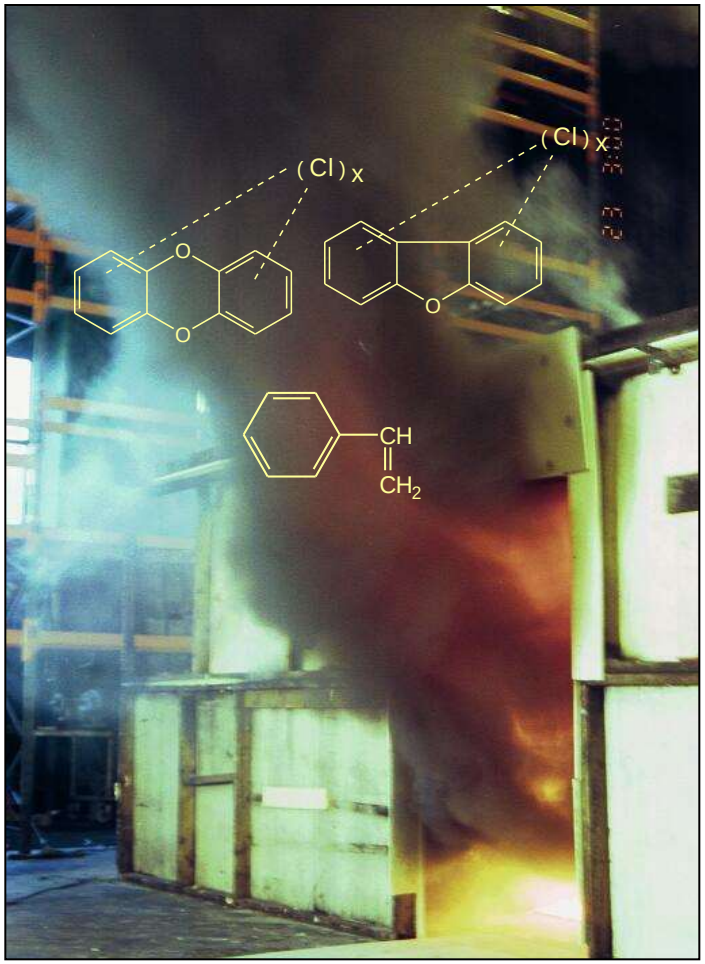
Fire Emissions



Types of emissions found in fire plume:

- Inorganic gases:
  - ✓ CO_2, CO, HCN, HCl…
- Large organic species:
  - ✓ VOC
  - ✓ PAH
  - ✓ Dioxins/furans

Fire Emissions



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  - ✓ PAH
  - ✓ Dioxins/furans

Determining factors

Ventilation

- ✓ Well-ventilated
- ✓ Under Ventilated

Type of Combustion

- ✓ smoldering
- ✓ flaming

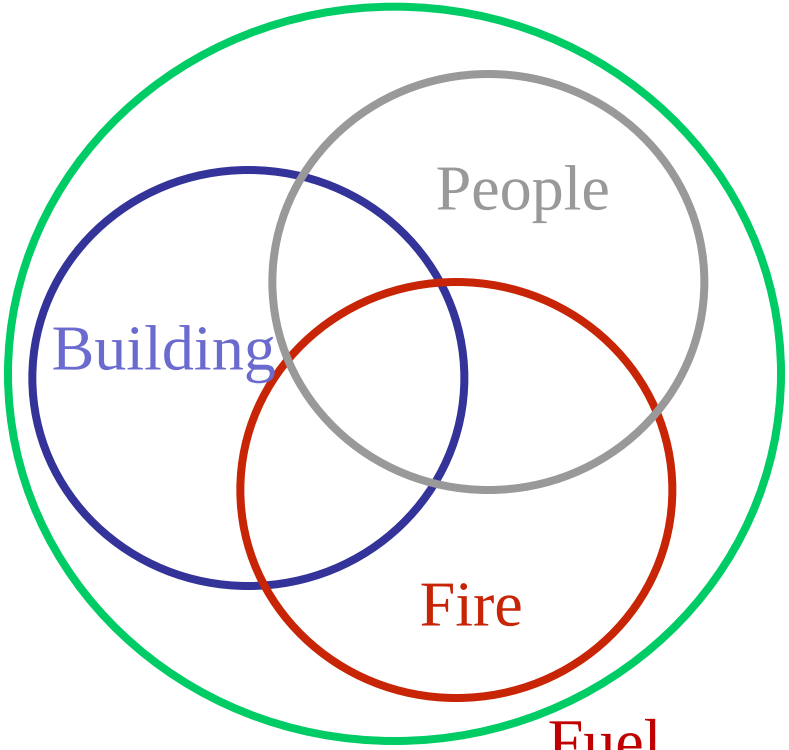
Fuel composition

- ✓ Carbon and Hydrogen only
- ✓ Chlorine, Nitrogen
- ✓Fillers and nano-fillers
- ✓Flame Retardants

Fire in Tyre Storage Facility in Canada

Sustainable and Resilient Building Design

Materials
Construction
Systems
Accessibility
Aesthetics
Comfort
Useability

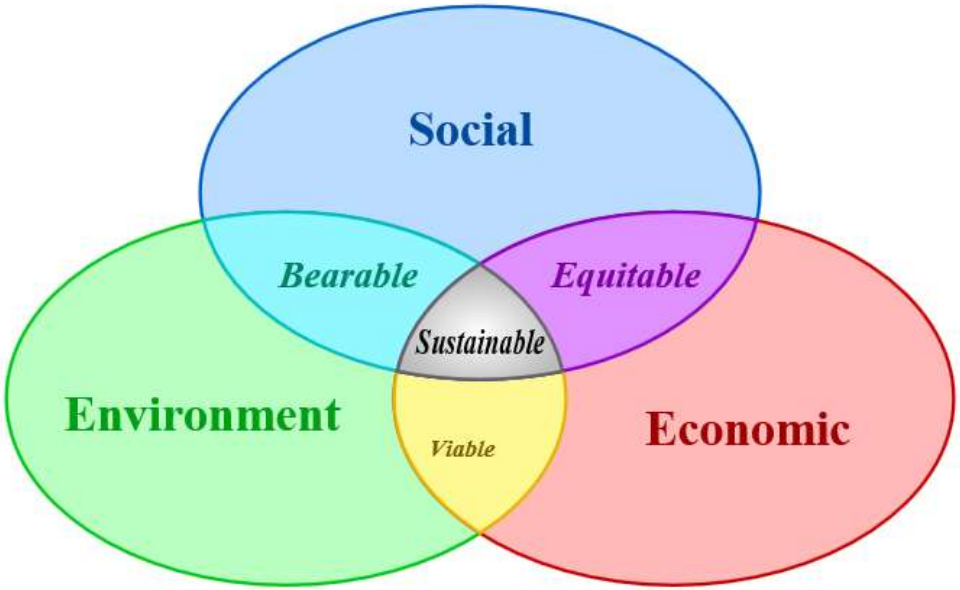


Human Factors
Decision-making
Response to Hazards
Risk Tolerance

Fuel
Ignition sources
Ventilation

What do we mean by sustainable?

- Environmentally friendly
- Can be maintained in the future
- Economics
- Social responsibility
- Resource use
- Land use
- Others???



…how do we measure it?

Life Cycle Assessment Framework

Goal and Scope Def.

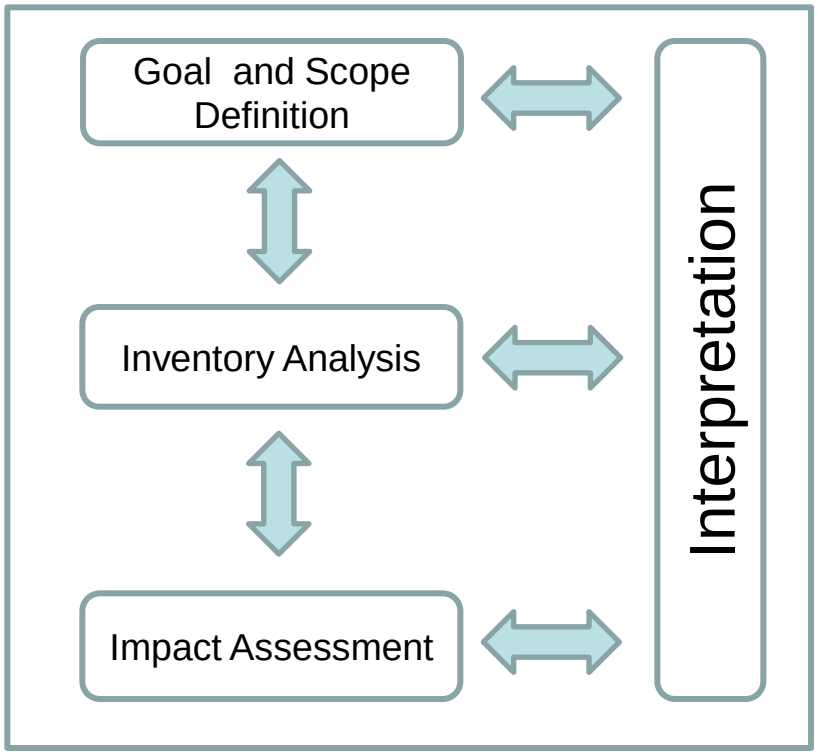
- ✓ System boundaries
- ✓ System environment
- ✓ Functional unit

Inventory Analysis

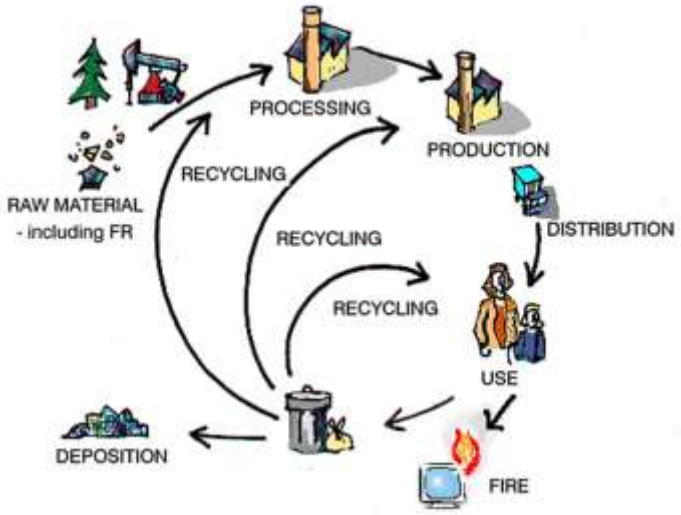
- ✓ Material flows
- ✓ Processes/activities

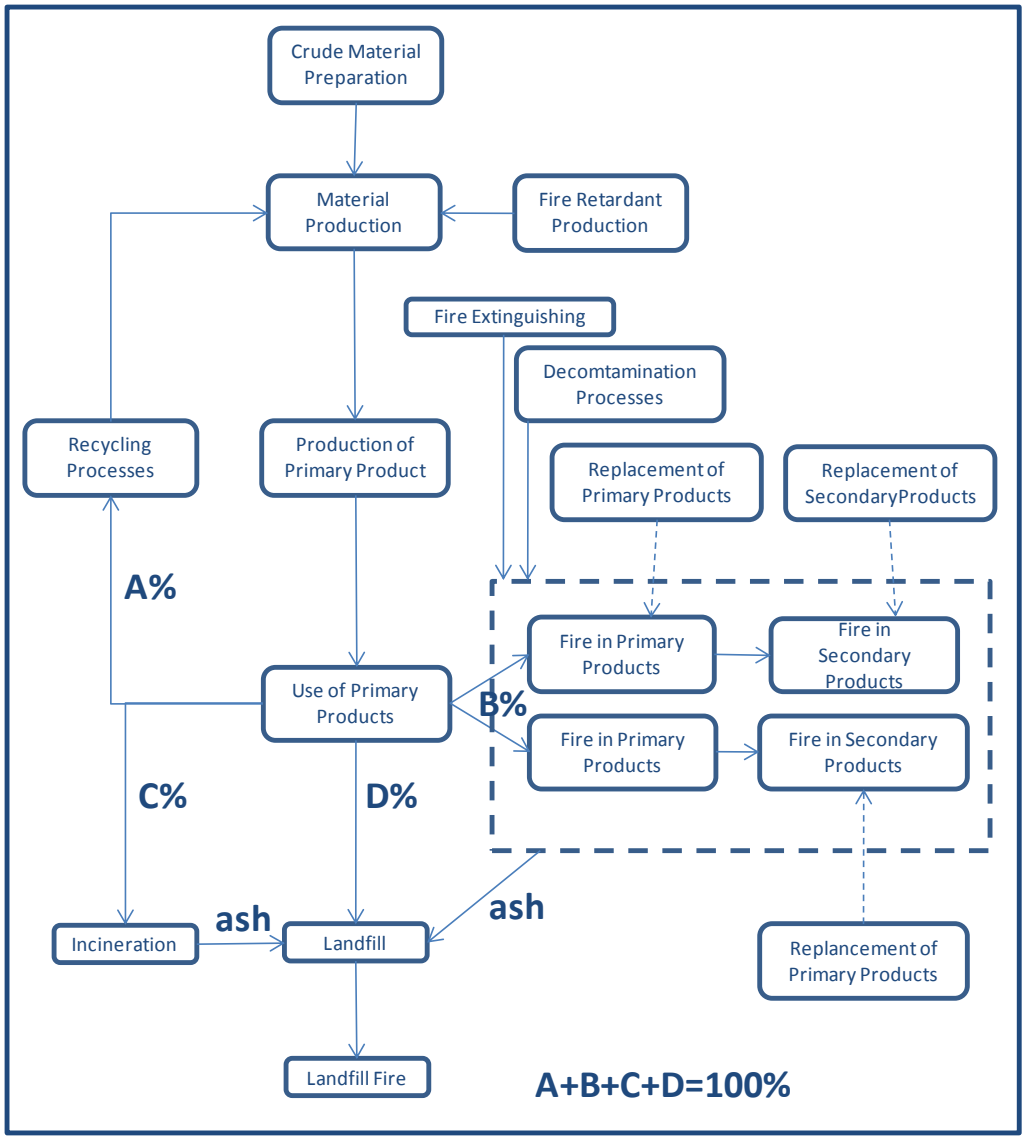
Impact Assessment

- ✓ Environmental impact
- ✓ Subjective, difficult



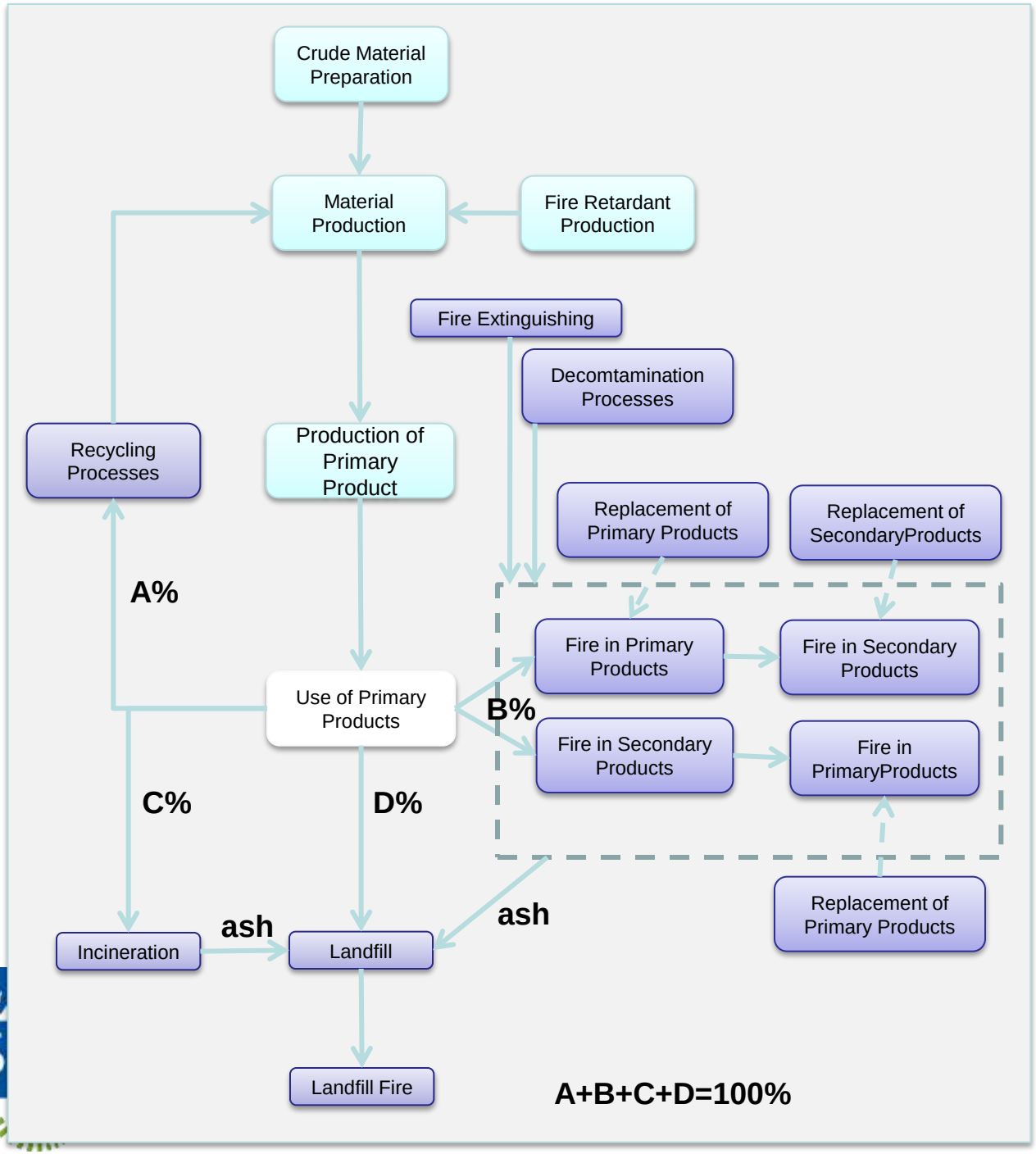
Fire-LCA


PROCESSING
PRODUCTION
RAW MATERIAL
- including FR
RECYCLING
RECYCLING
RECYCLING
DISTRIBUTION
USE
DEPOSITION
FIRE


Crude Material Preparation
Material Production
Fire Retardant Production
Fire Extinguishing
Decomtamination Processes
Recycling Processes
Production of Primary Product
Replacement of Primary Products
Replacement of SecondaryProducts
A%
Fire in Primary Products
Fire in Secondary Products
Use of Primary Products
B%
Fire in Primary Products
Fire in Secondary Products
C%
D%
ash
ash
Incineration
Landfill
Replancement of Primary Products
Landfill Fire
A+B+C+D=100%

Fire-CBA

Module	Comment
Production	All additional costs for fire safety when comparing 2 products, e.g. flame retardants, fire resistant material etc
Use/ Transport	Generally there are no additional costs in this phase due to the level of fire performance.
Destruction/ Disposal	Special costs associated with isolated stream disposal.
Fire	Extinguishment, sanitation, treatment of injuries/deaths, property costs.
Chemical Exsposure	Not strictly a module but needs to be considered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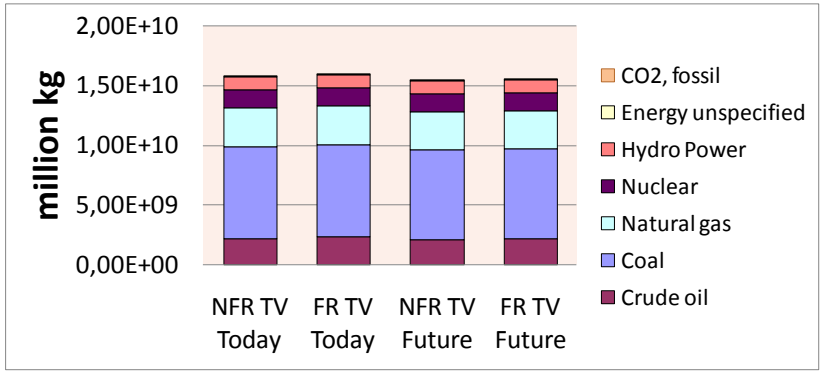
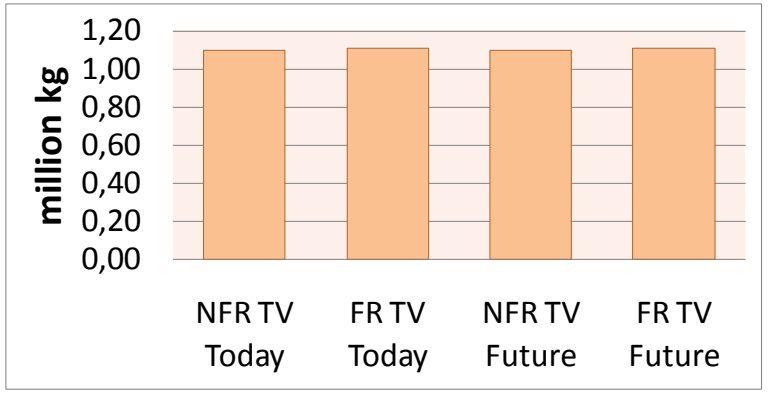
Use of Primary Products
B%
Fire in Secondary Products
Fire in PrimaryProducts
C%
D%
Replacement of Primary Products
ash
ash
Incineration
Landfill
Landfill Fire
A+B+C+D=100%
Production module
Fire module
Use module
End-of-Life module
Chemical Exposure
Transport

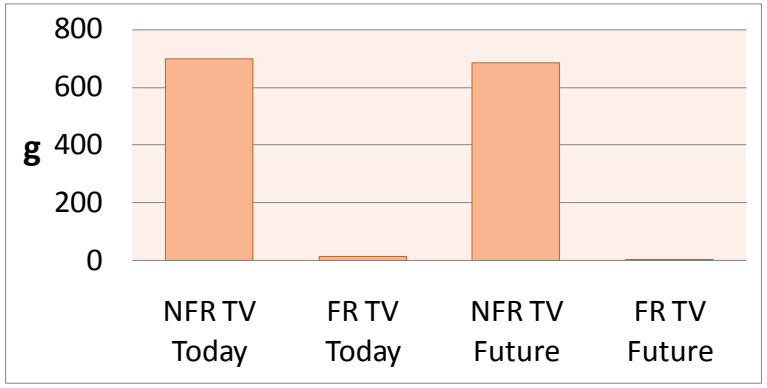
TV Case Study – Fire-LCA



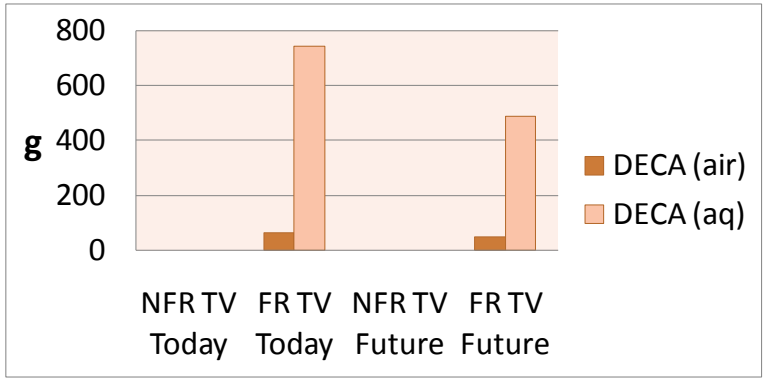
a) Energy use.



b) Carbon dioxide emissions.



c) PAH emissions.



d) Deca-BDE emissions to air and water.

Conclusions – Fire-LCA Case Study

- Minor energy difference between US and European TVs
- Fires insignificant source of CO, CO_2, NO_x ….
- European:US TV-difference most marked for large organic species
- PAH most significant toxicologically
- Full risk assessment must consider risk for death and injury:

TV Case Study – Fire-CBA

Case #	Values used	Cost (Million US$)	Benefit (Million US$)	Result (Million US$)
1	Nominal value according to table 3	409	1 215	806
2	Muir data for number of lives saved and injuries avoided	409	458	49
3	No injuries avoided	409	865	456
4	No cost for house fires included	409	1 050	641
5	Using Maximum house construction cost	409	1 333	924
6	Minimum cost for disposal	142	1 215	1073
7	No health cost included	383	1 215	832
8	No discount	409	1 414	1005
9	10% discount	409	921	512

Conclusions – Fire-CBA Case Study

Costs: incremental increases in cost to flame retard a product; additional costs for disposal

Benefits: lives saved; injuries avoided; capital costs avoided

Application to DecaBDE use in TV-sets

- No cost assigned to the injuries due to exposure to DecaBDE
- Incremental cost of manufacture of the FR and disposal of FR material included
- Cost of lives lost, injuries treated and capital costs associated with fires included

…Between US$49 – 1 073 million can be saved each year by use of high level of fire performance in TV-sets.

Is there a difference in emissions between FR/nFR?

Main questions:

- Are emissions from fires more toxic if the materials contain FRs?
- Is there an increased risk to fire fighters due to FRs in fires?

Nio emissions scenarier

1. Reference room with sofa containing non-flame retardant covering and foam, burning together with the whole room
2. Reference room with a sofa containing deca-BDE as a back-coating to the cover and TCPP-melamine foam, burning together with the whole room
3. Sofa containing non-flame retardant covering and foam, burning alone in reference room
4. *Sofa containing deca-BDE as a back-coating to the cover and TCPP-melamine foam, burning alone in the reference room*
5. Reference room with TV containing a non-flame retardant enclosure and TBBP-A in the circuit boards, burning together with the whole room
6. Reference room with TV containing deca-BDE in the enclosure and TBBP-A in the circuit boards, burning together with the whole room
7. TV containing a non-flame retardant enclosure and TBBP-A in circuit boards, burning alone in the reference room
8. *TV containing deca-BDE in the enclosure and TBBP-A in the circuit boards, burning alone in a reference room*
9. Real fire in an apartment with information concerning soot, ash and debris.

Scenario	1 Room Non-BFR Sofa	2 Room BFR-sofa	3 Non-BFR sofa	4 BFR-sofa	5 Room Non-BFR TV	6 Room BFR-TV	7 Non-BFR TV	8 BFR-TV
Compound	***Hazards***							
Inorganic:								
CO_2	+++	+++	++	++	+++	+++	++	+
CO	+++	+++	++	+++	+++	+++	++	++
HCN	++	+++	-	++	+++	+++	-	-
HCl	++	++	+++	+++	++	+++	++	++
NH_3	++	++	+	+	-	++	-	-
SO_2	+++	+++	-	-	-	+++	-	-
NO	++	++	++	++	-	-	-	-
Br (from HBr)	-	+	-	+	-	++	-	+++
Sb	-	+	-	+	-	-	-	+++
VOCs:								
Benzene	+++	+++	++	+++	+++	+++	+++	+++
Toluene	-	-	-	-	-	+	-	+
Styrene	-	+	-	-	+	+	+	+
Phenol	+	+	-	+	-	-	+	+
Benzonitrile								
PAHs:								
Naphtalene	+	+	-	-	++	++	+	+
Acenaphthalene								
Acenaphthene								
Fluorene								
Phenanthrene								
Anthracene	++	++	+	+	++	+++	++	++
Fluoranthrene								
Pyrene								
Benzofluorenes								
Benzo(a)anthracene								
Chrysene	++	++	-	+	++	+++	++	+++
Benzofluoranthenes	+++	+++	+	+	+++	+++	++	
Benso(e)-pyrene								
Benso(a)-pyrene	++	++	-	+	++	+++	+	++
Perylene								
Indeno(1,2,3-c,d)pyrene	++	++	-	+	+++	+++	+	++
Benzo(g,h,i)perylene								
Dibenzo(a,h)anthracene								
Coronene								

Scenario	1 Room Non-BFR Sofa	2 Room BFR-sofa	3 Non-BFR sofa	4 BFR-sofa	5 Room Non-BFR TV	6 Room BFR-TV	7 Non-BFR TV	8 BFR-TV
PCDD/PCDFs and PBDD/PBDFs:								
TCDD-eq. (Cl-)	++	+++	+	+++	++	++	+++	+++
TCDD-eq. (Br-)	+++	+++	++	+++	+	++	++	+++
Total TCDD-eq.(Cl-+Br-)	+++	+++	++	+++	++	++	+++	+++
PBDEs:								
Total PBDEs								
TBBPA								
Isocyanates/amines:								
2,4 - TDI	+		+	+				
2,6 - TDI	+		+	+				
phenyl isocyanate								
methyl isocyanate	++	++	++	++				
ethyl isocyanate								
isocyanic acid								
2,4 - TAI								
2,6 - TAI								
2,4 - TDA								
2,6 - TDA								

Conclusions

- 9 scenarios:
  - ✓ 1-8 – exposure to gaseous emissions
  - ✓ 9 - skin exposure to contaiminated soot
- Scenario 9 not studied in detail
- Minimal difference in exposure risk for scenarios 1-8
- Exposure to fire gases is dangerous independent of the presence or absence of FRs.
- It is important that suitable protective gear is used in all phases of a fire operation, i.e. also in clean-up