NPTEL ONLINE CERTIFICATION COURSES

Course Name: Introduction to Environmental Engineering and Science – Fundamentals and Sustainability Concepts

Faculty Name: Dr. Brajesh Kumar Dubey

Department : Civil engineering

Topic Environmental Risk Assessments with Concepts of EIA and LCA

Lecture 26: Environmental Risk

CONCEPTS COVERED

Concepts to be Covered

- Environmental Risk Assessment
- EIA and
- LCA

Risk Assessment

What is the potential event

What can be cause

What can be the consequences?

Risk Assessment

In 2017, 1.47 lakhs people died in road accident in India, which is equivalent to the entire population of Shilong, capital of Meghalaya.

What we can do?

Risk Assessment

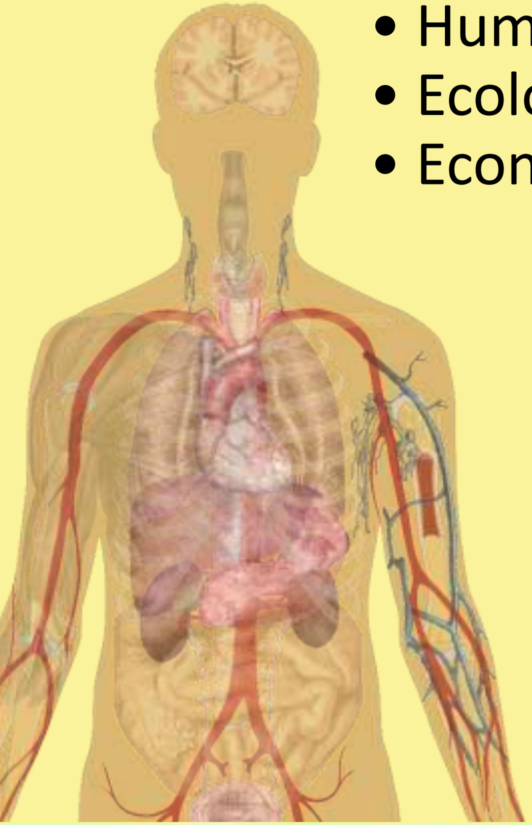
7000 people die annually in U.S. from falls in their homes

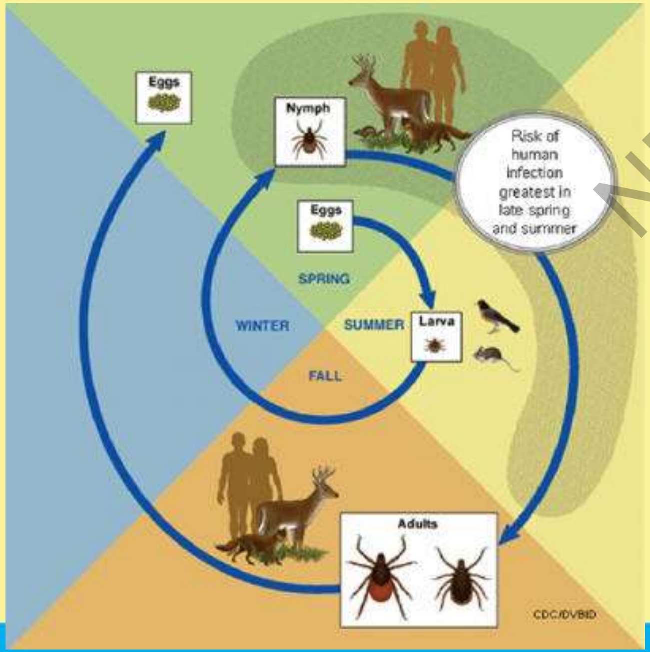
but ... most are over age 65, so should the rest of us ignore this?

It's all about CHOICES!!!!!

Risk Assessment

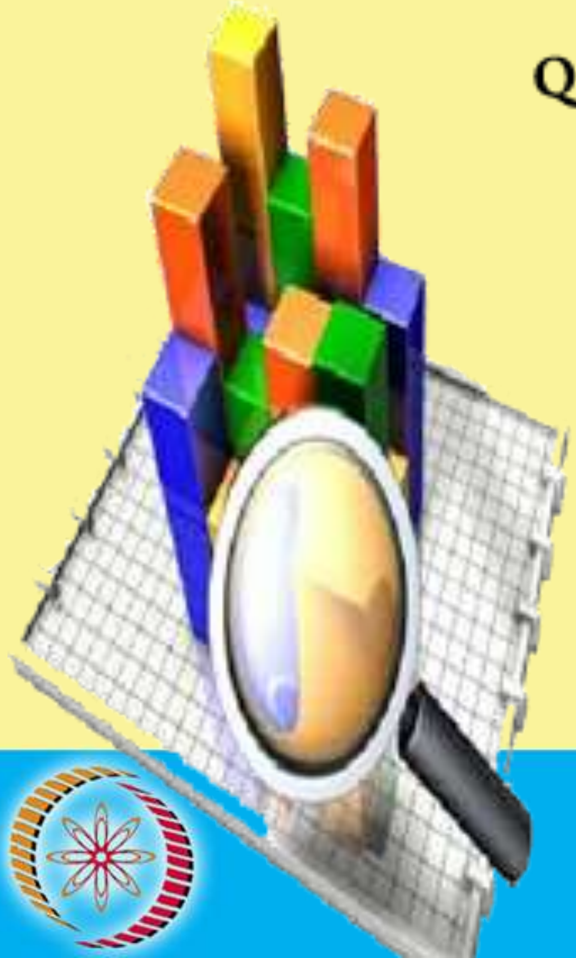
- Risk
  – The likelihood of harm, including both acute [short term] and chronic [longer term] effects to
    - Human health and the quality of human life
    - Ecological systems
    - Economic systems





Risk Assessment

- Risk assessment
    - – The process by which the form, dimension and characteristics of risk are estimated
    - – Utilize both qualitative and quantitative approaches



Quantitative and Qualitative

Risk Assessment

- Risk Management

  The process by which a risk is controlled or reduced

Risk (regulatory decisions)

- Risk basis for regulatory decisions
  - Cancer endpoint "one in a million" [1 x 10-6]
  - Epidemiological basis for human risk calculations
  - Animal testing where human data are unavailable [most data are animal testing data except for those rare situations where a human exposure event has been documented]

Familiar Risks

- Reference point = 1 in a million (1x10-6)

below which USDA doesn't consider risk from a food additive to be a concern

Minimal risk = 1x10-10 to 1x10-12

Very high risk = 1x100 to 1x10-2

Examples	Risk
Drowning in a tub/year	10^{-5} to 10^{-6}
Death in airplane crash	10^{-5} to 10^{-6}
Death by automobile accident	1.7×10^{-4}
Death by lightning strike	10^{-3} to 10^{-4}

Basic Principles

- Risk assessment – a determination of the probability that an adverse effect will be produced
  - All human activities have some risk
  - Concerned mostly with risk from exposure to chemicals
- Risk assessment – extended definition
  - A methodological approach where chemical exposures are identified, analyzed for dose-response relationships and quantified for risk estimates
  - Ideal approach for a risk assessor –

- Calculate amount of chemical absorbed into human body
  Compare the "absorbed dose" with EPA's "safe dose" for non-carcinogens, i.e. the reference dose
  Note – EPA does not recognize a "safe dose" for carcinogens; "any" level of exposure has some cancer risk
  A "risk specific dose" is used by EPA to assess exposure to carcinogens

Basic Principles

- – Ideal approach for a risk assessor –

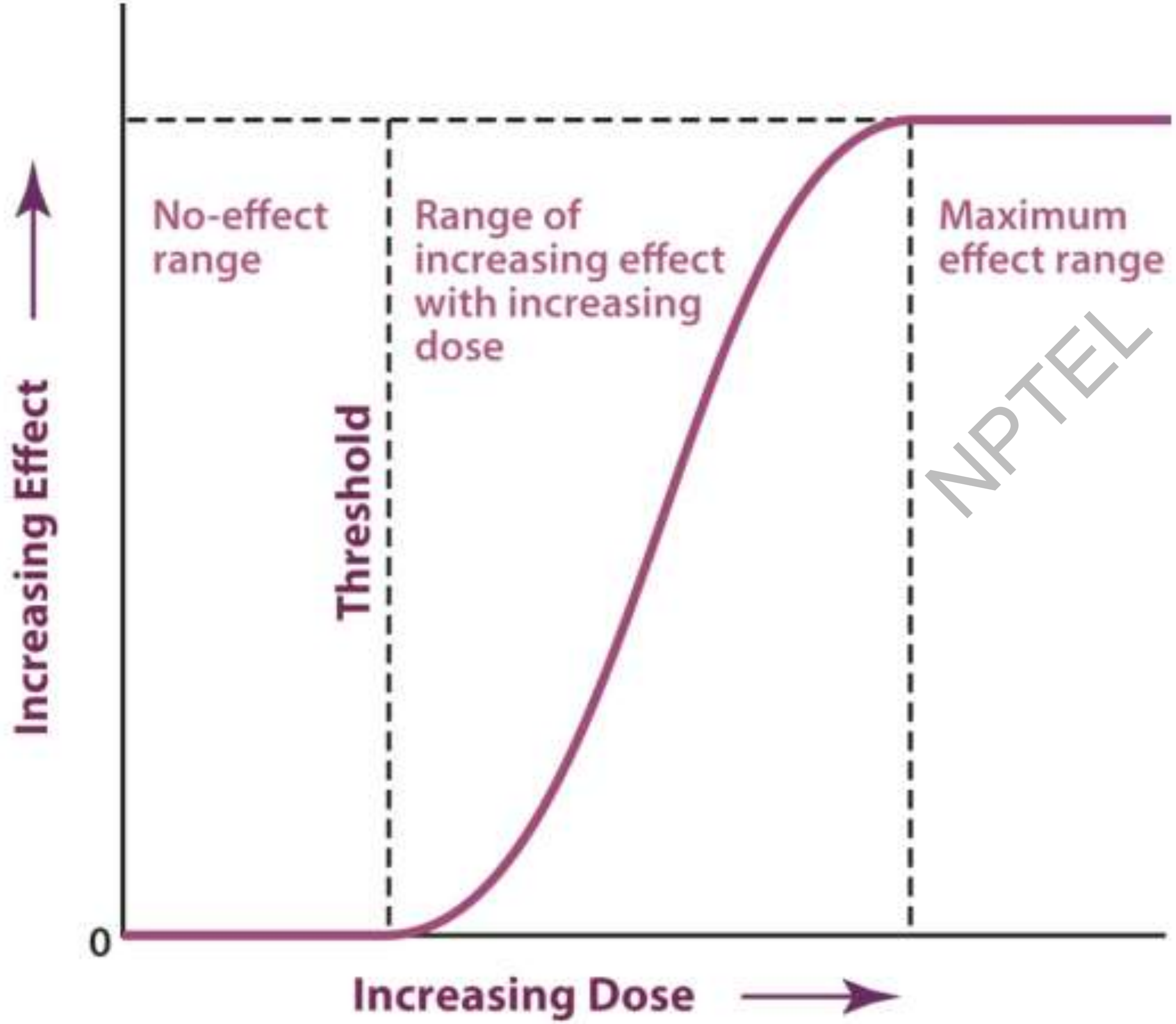
Calculate amount of chemical absorbed into human body

Compare the “absorbed dose” with EPA’s “safe dose” for non-carcinogens, i.e. the reference dose

Note – EPA does not recognize a “safe dose” for carcinogens; “any” level of exposure has some cancer risk

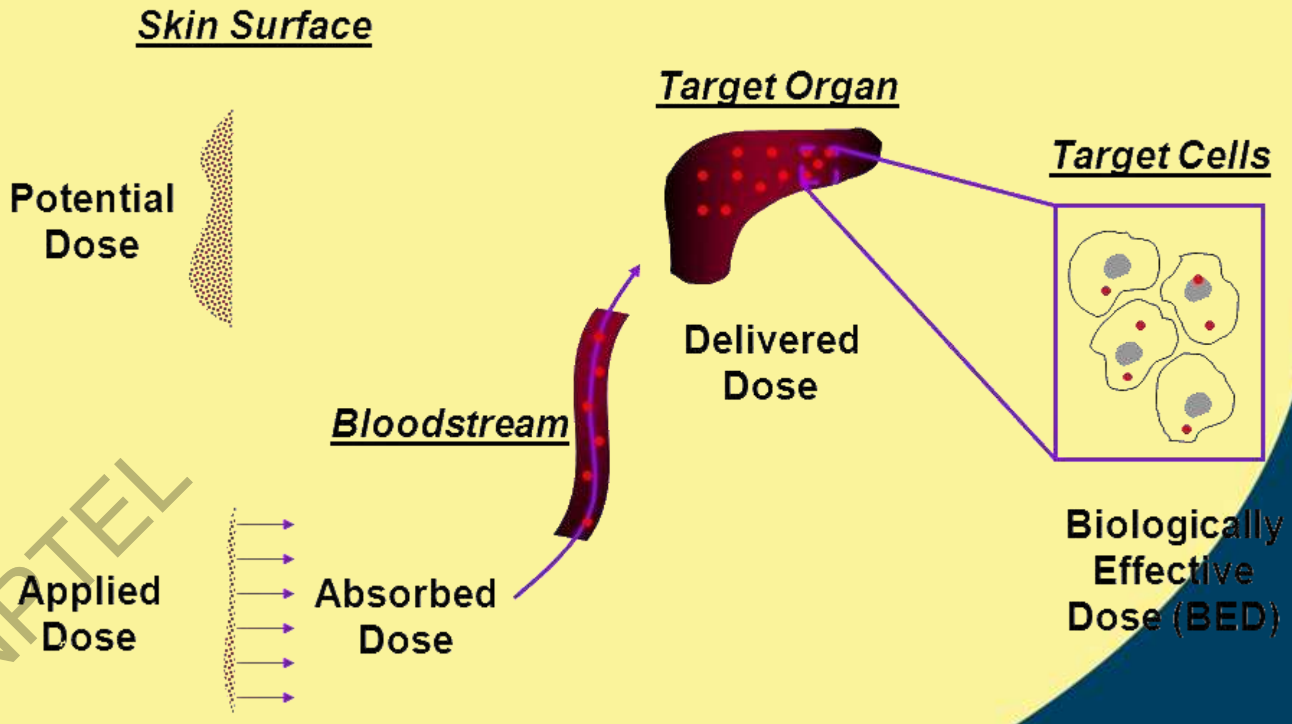
A “risk specific dose” is used by EPA to assess exposure to carcinogens

Dose-response Curve



Risk Definitions 1

- Applied dose – The amount of chemical in a medium that is available for uptake
- Absorbed dose – The amount of chemical absorbed into the body [related to the fraction of applied dose that is absorbed; need to consider route of exposure [ingestion, skin, inhalation]
- Reference dose [RfD] – The dose of a non-carcinogen that is believed safe for humans [usually extrapolated from animal toxicity data]



Risk Definitions 2

- Risk specific dose [RsD] – The dose at which one person in a million exposed people will develop a disease (risk = $1/10^6$)
- Hazard index [HI] = Ratio of absorbed dose to the RfD
  – HI < 1 is an "acceptable" situation
  – HI > 1 needs the chemical concentration to be decreased
- Risk management (another definition) – The process of factoring the risk assessment vs. possible alternative actions
  – Cost/benefit considerations
  – Consumer needs
  – Alternative chemicals
  To determine how best to regulate exposure to the chemical

Risk Assessment Process at Site with Drinking Water 1

(1) Hazard identification
- What chemicals are present? Concentrations?
- Carcinogens or non- carcinogens?

(2) Dose – response assessment
- Dose vs response relationships?
- Data validation
- Discover RfD and/or RsD data from animal studies

Risk Assessment Process 2

- Human exposure assessment
  - Need to make exposure assumptions
  - Example for drinking water exposure
    - Assume 0.5 mg/L Zn in drinking water
    - Assume adult water intake = 2 L/day
    - Adult weight = 70 kg
    - Dose = (0.5 mg/L) (2 L/day)/ 70 kg weight = 0.0143 mg/kg/day

Risk Assessment Process 3

- Risk estimation
  - Compare absorbed dose to RfD or RsD
  - Clean-up required if risk > 1/106 or HI > 1
  - For Zn example, RfD = 0.2 mg/kg/day

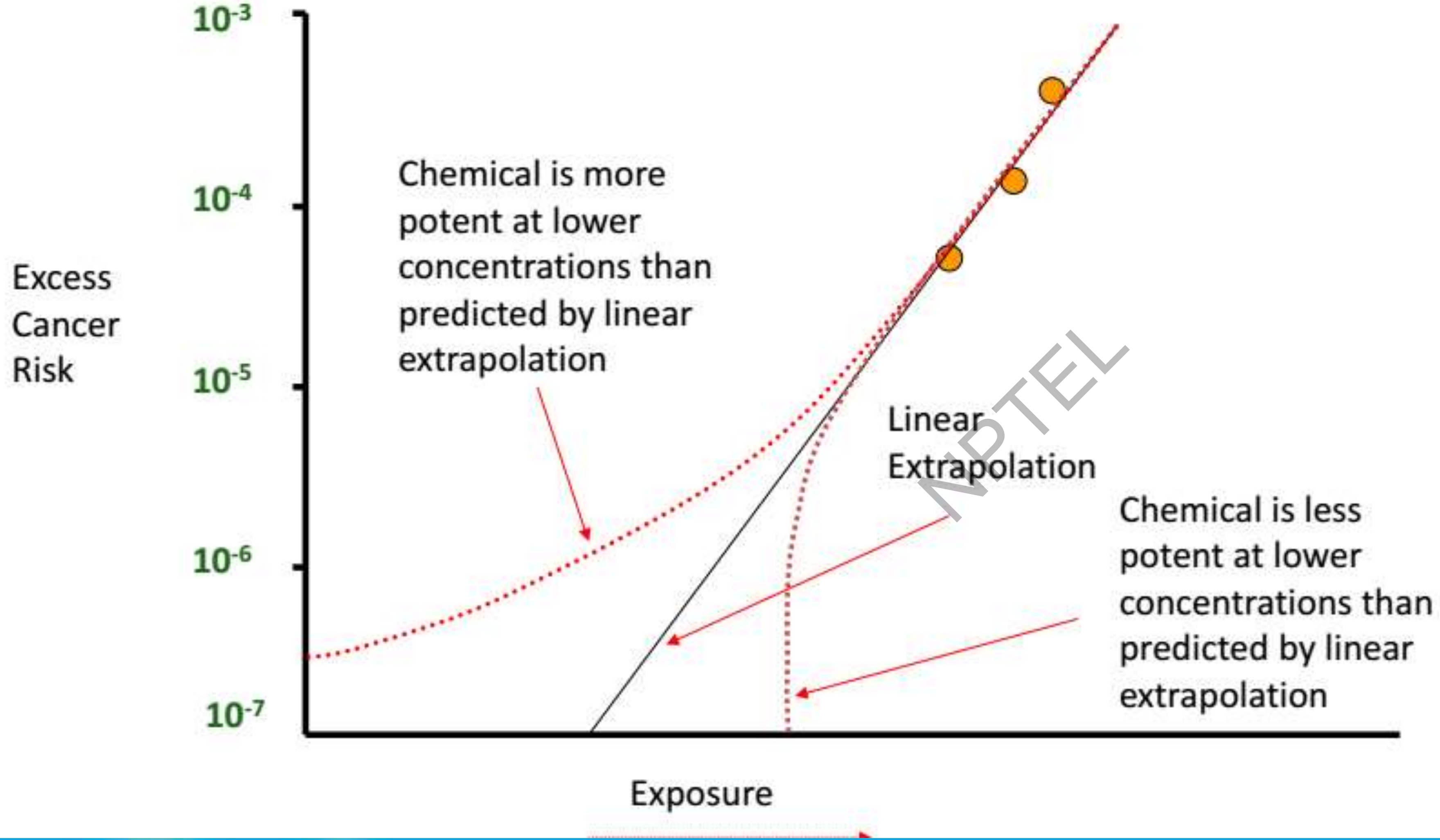
  - $HI = \dfrac{0.0143 \text{ mg/kg/day}}{0.2 \text{ mg/kg/day}} = 0.0715$

Therefore, since HI < 1, no cleanup is required Assume no other significant contaminants present

Assessing Risk

- The toxicity information (RfD and SF) for chemicals in a waste, along with estimates of exposure duration and frequency, can be used to assess the risk posed by a waste or contaminated soil, or can be used to set protective limits.

Oral cancer slope factor



Assessing Risk:
Equation for Drinking Water Standard or Target Level (Carcinogen)

Target cancer risk (unit less)

Body weight (kg)

Standard (mg/L) → $$C = \frac{TR \times BW}{CSF_o \times WC}$$

Oral cancer slope factor (mg/kg-day)$^{-1}$

Average water consumption rate (L/day)

Equation for Drinking Water Standard or Target Level (Non-Carcinogen)

Oral cancer slope factor $(mg/kg\text{-}day)^{-1}$

Body weight (kg)

Standard (mg/kg)

$$C = \frac{TR \times BW}{RFD_o \times IR}$$

Average water consumption rate (L/day)

Example Equation for Clean Soil Standard or Target Level (Carcinogen, Ingestion Route Only)

Target cancer risk (unit less)

Body weight (kg)

C (mg/kg)

$$C = \frac{TR \times BW}{CSF_o \times IR}$$

Oral cancer slope factor $(mg/kg\text{-}day)^{-1}$

Ingestion Rate (mg/day)

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Lecture 27: Risk Assessment-Steps and EIA

Risk Assessment

The risk analysis process includes four steps

Step 1
Hazard identification

Step 2
Dose-response evaluation

Step 3
Exposure assessment

Step 4
Risk characterization

Risk Assessment

Risk assessment provides a qualitative or quantitative estimation of the likelihood of adverse effects that may result from exposure to specific health hazards or from the absence of beneficial influences.

RISK ASSESSMENT MATRIX				
SEVERITY / PROBABILITY	Catastrophic (1)	Critical (2)	Marginal (3)	Negligible (4)
Frequent (A)	High	High	Serious	Medium
Probable (B)	High	High	Serious	Medium
Occasional (C)	High	Serious	Medium	Low
Remote (D)	Serious	Medium	Medium	Low
Improbable (E)	Medium	Medium	Medium	Low
Eliminated (F)	Eliminated			

Risk Management

- ❖Follows risk characterization
- ❖Seeks to control exposures to toxic chemicals in the environment.
- ❖Leads into Law & Policy

Dredging operations to remove PCB-laden sediment from the Upper Hudson River commenced in May 2009. The second phase of this Superfund remediation effort is scheduled to get underway in 2012.

Former Ukrainian president Viktor Yushchenko is shown in photos from March 2002 (left) and December 2004 (right). Yushchenko was scarred by deliberate dioxin poisoning during his 2004 presidential candidacy.

Libby, Montana, a town of 3,000 along the Kootenai River, has emerged as the deadliest Superfund site in U.S. history due to decades of contamination with asbestos fibers from a near vermiculite mine.

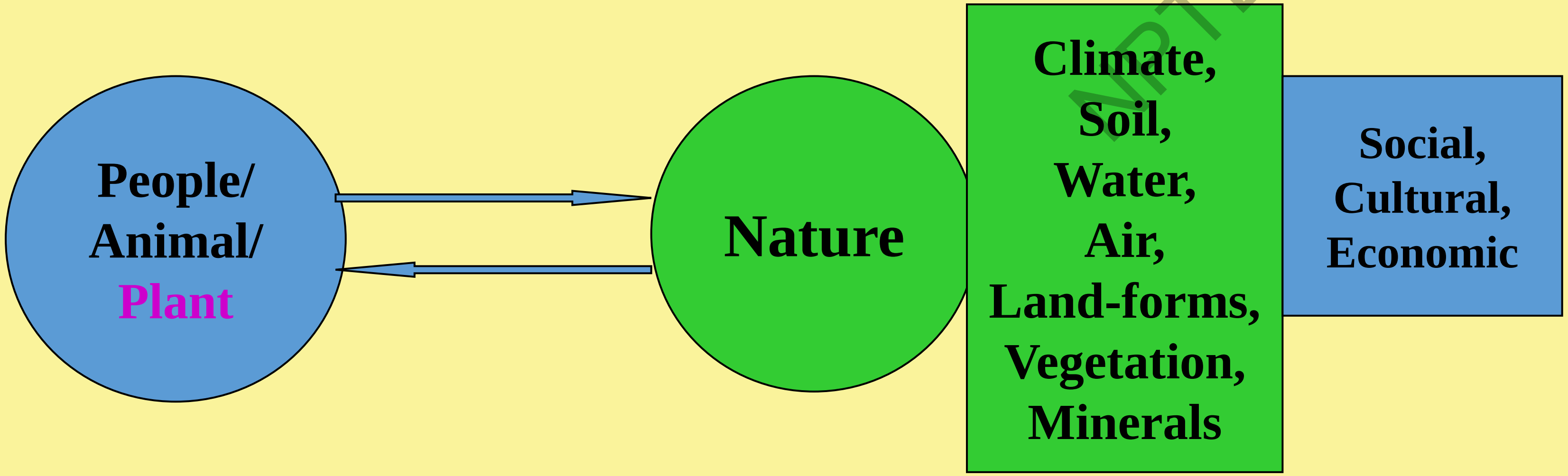
Workers in full-body protective gear dampen and remove asbestos-containing materials from a high school.

What is Environment?

The dictionary meaning of the term environment is surrounding.

What continues surrounding?

It encompasses all external conditions influencing development or growth of people, animals and/or plants.



National Environmental Policy Act of USA:

Environment include physical, social, cultural, economic and aesthetic dimension.

Environment means the whole complex of physical including chemical, social, cultural, economic, and aesthetic factors which affect individuals and communities and ultimately determine their form, character, relationship and survival.

Different elements of Environment

- Physical Environment (include Physical, chemical and biological factors)
- Social Environment (social and cultural life of the people)
- Economic Environment (employment and unemployment levels, average income, economic base, etc.)
- Aesthetic Environment (historical, archaeological, architectural objects or sites; scenic areas, views and landscape)

Physical Environment

- Land and Climate
- Vegetation, wildlife and Natural Areas
- Surrounding Land uses and physical character of the area
- Infrastructure
- Air pollution sources and levels
- Noise pollution sources
- Water pollution sources and levels

Impact Assessment:

systematic analysis of the problem being addressed, the objective, alternative options to reach the objective and their likely impacts … through a structured way …. (*from EU Guidelines*)

Why do impact assessments?

Need results from **problems of choice**, where decision-makers face one or more options in a given context

(e.g. choice *among* projects; choice *within* a project; policy impacts ('trade-

Ensures coherence between development interventions

Will **support better policy-making** but cannot be a substitute for it

Law, Policies and Institutional Arrangements

When establishing or strengthening an EIA system, there is an opportunity to build upon the experience of others and to move towards **legal and policy** frameworks that **support environmental sustainability**.

- **More systematic procedures** for EIA implementation, quality control, compliance and enforcement;
- **Integrated consideration** of biophysical, social, risk, health and other impacts;
- **Extended temporal and spatial frameworks**, which include cumulative, trans-boundary and ecosystem-level effects and, to a lesser extent, global change;

Law, Policies and Institutional Arrangements

When establishing or strengthening an EIA system, there is an opportunity to build upon the experience of others and to move towards **legal and policy** frameworks that **support environmental sustainability**.

- Increasing provision for strategic environmental assessment (SEA) of policy, plan and programme proposals;
- Incorporation of sustainability perspectives and principles into EIA and SEA processes; and
- Greater linkage of EIA systems with other planning, regulatory and management regimes.

What is EIA?

Environmental assessment (EIA) is the term used for the assessment of the environmental consequences (positive and negative) of a plan, policy, program, or project prior to the decision to move forward with the proposed action.

The Evolution of EIA

Pre-1970s: The Project evaluation is dominated by economic and technical criteria

1970s: practice of EIA in some developed countries; wider attention to environmental impacts since mid-1980s

1980s: consideration of social and institutional aspects

1980s and early 1990s: thematic assessments by donor agencies

Late 1990s: Integrated approaches to impact assessment in varied forms

The Evolution of EIA

INDIAN CONTEXT

In order to predict environmental impacts of any development activity and to provide an opportunity to mitigate against negative impacts and enhance positive impacts, the Environmental Impact Assessment (EIA) procedure was developed in the 1970s

the Ministry of Environment and Forests at New Delhi introduced the EIA law through a gazette notification passed on 27 January 1994, for obtaining "environmental clearance" for certain types of projects

Why EIA?

The purpose of the assessment is to ensure that decision makers consider the environmental impacts when deciding whether or not to proceed with a project.

The International Association for Impact Assessment (IAIA) defines an environmental impact assessment as "the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made."

IAIA
International Association for Impact Assessment

Why EIA?

In principle, environmental assessment can be undertaken for Individual projects such as a dam, motorway, airport or factory and call it as 'Environmental Impact Assessment‘ (EIA).
Plans, programs and policies and call it as 'Strategic Environmental Assessment‘ (SEA).

Learning objectives

After completing this Unit, you should be able to:

1. Discuss environmental impact assessment (EIA) as an environmental management tool;
2. trace the evolution of EIA;
3. Discuss what forecasting of environmental changes entails;
4. Explain strategic environmental assessment (SEA);
5. List and comply with the environmental clearance procedures in India;
6. Plan and carry out an environmental impact assessment study.

Benefits of Environmental Assessment

Most governments and donor agencies acknowledge the contribution of EA to improve project design. The weakness of EA in the past has been largely due to poor techniques and the failure to pay attention to findings at the implementation stage (Environmental Science Services Administration Technologies 1994).

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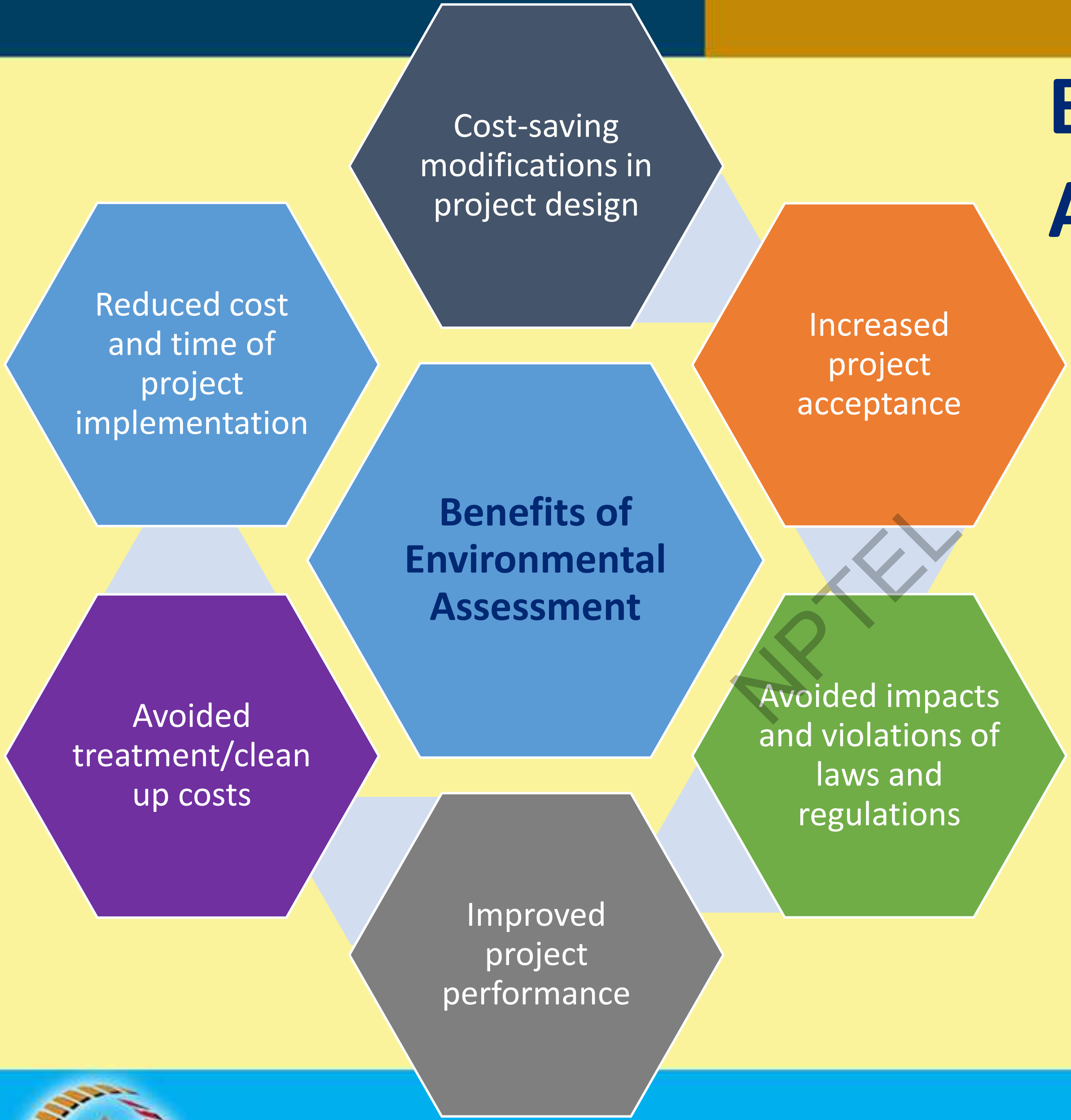
Lecture 28: Environmental Impact Assessment

Benefits of Environmental Assessment

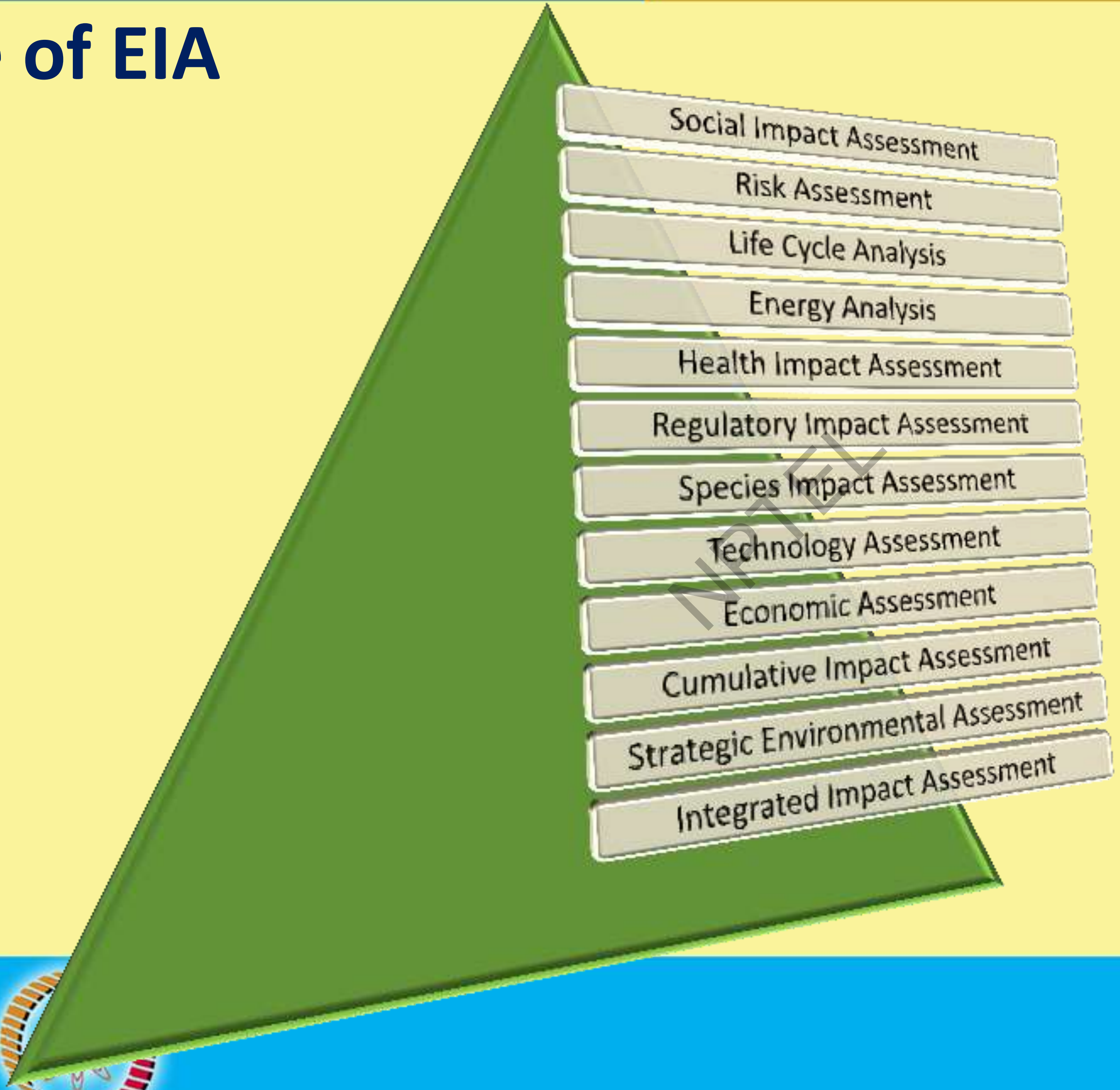


Benefits to local communities from taking part in environmental assessments

Principle of EIA

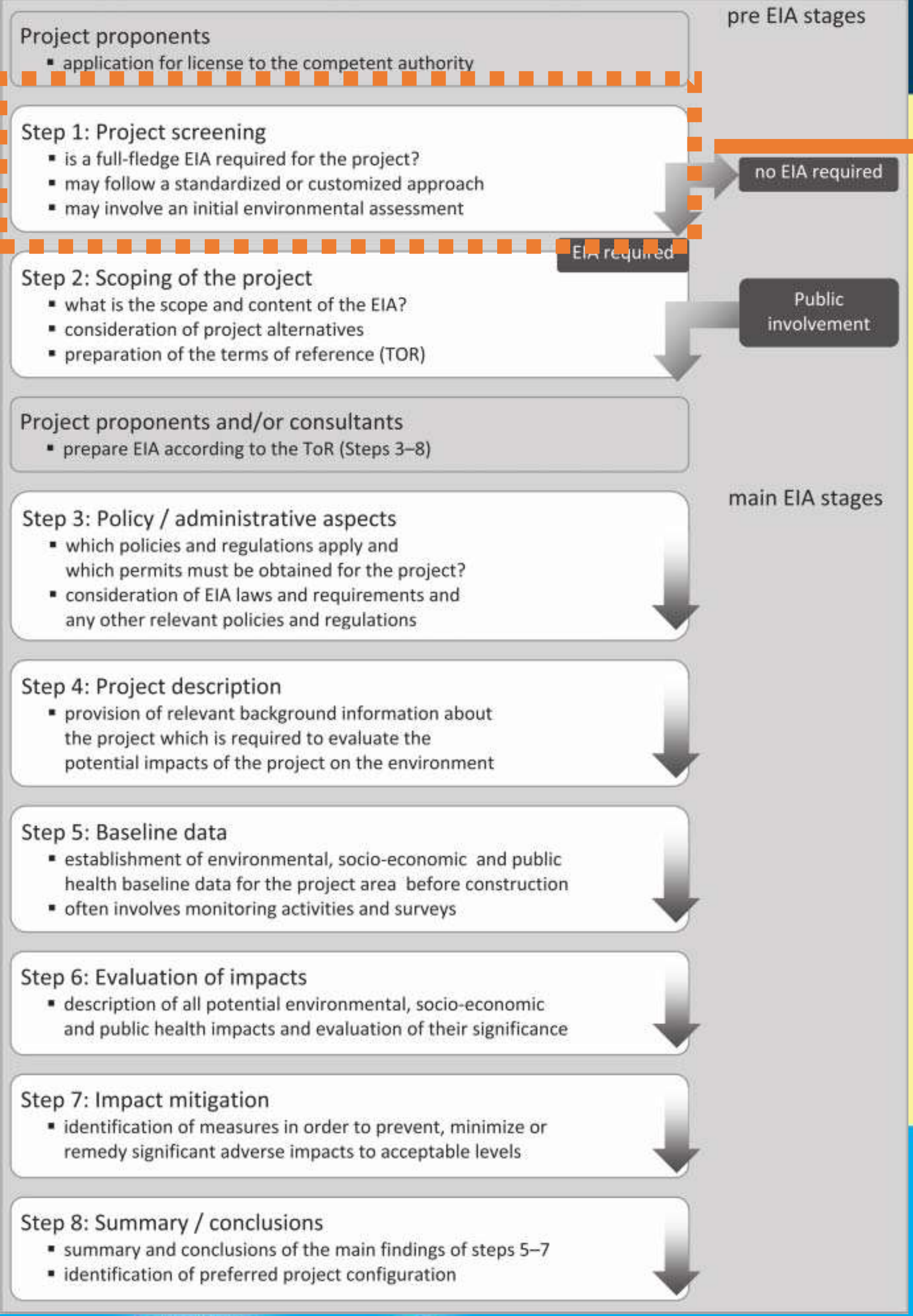
It is important to recognize that there is a general principle of assessment that applies to EIA, and to other assessment processes. There are several other processes that relate closely to the review of environmental impacts that may result from a proposed project. The following are well recognized processes:

Principle of EIA

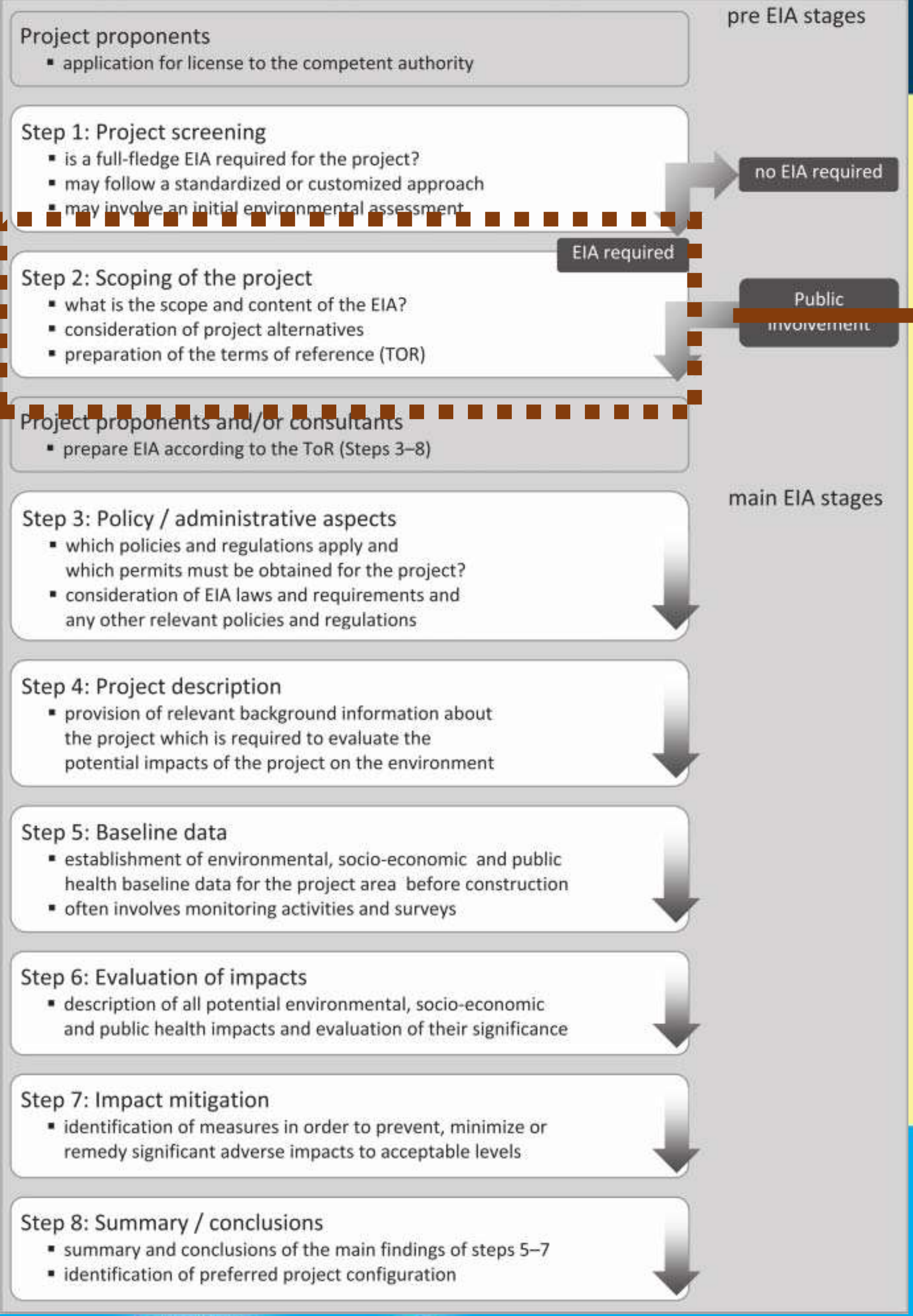


Purposes of EIA

- To facilitate decision-making
- To aid in the formation of development
- To be an instrument for sustainable development



Screening: This entails the application of EIA to those projects that may have significant environmental impacts. It is quite likely, however, that screening is done partly by the EIA regulations, operating in a country at the time of assessment.



Scoping: This step seeks to identify, at an early stage, the key, significant environmental issues from among a host of possible impacts of a project and all the available alternatives.

Scoping

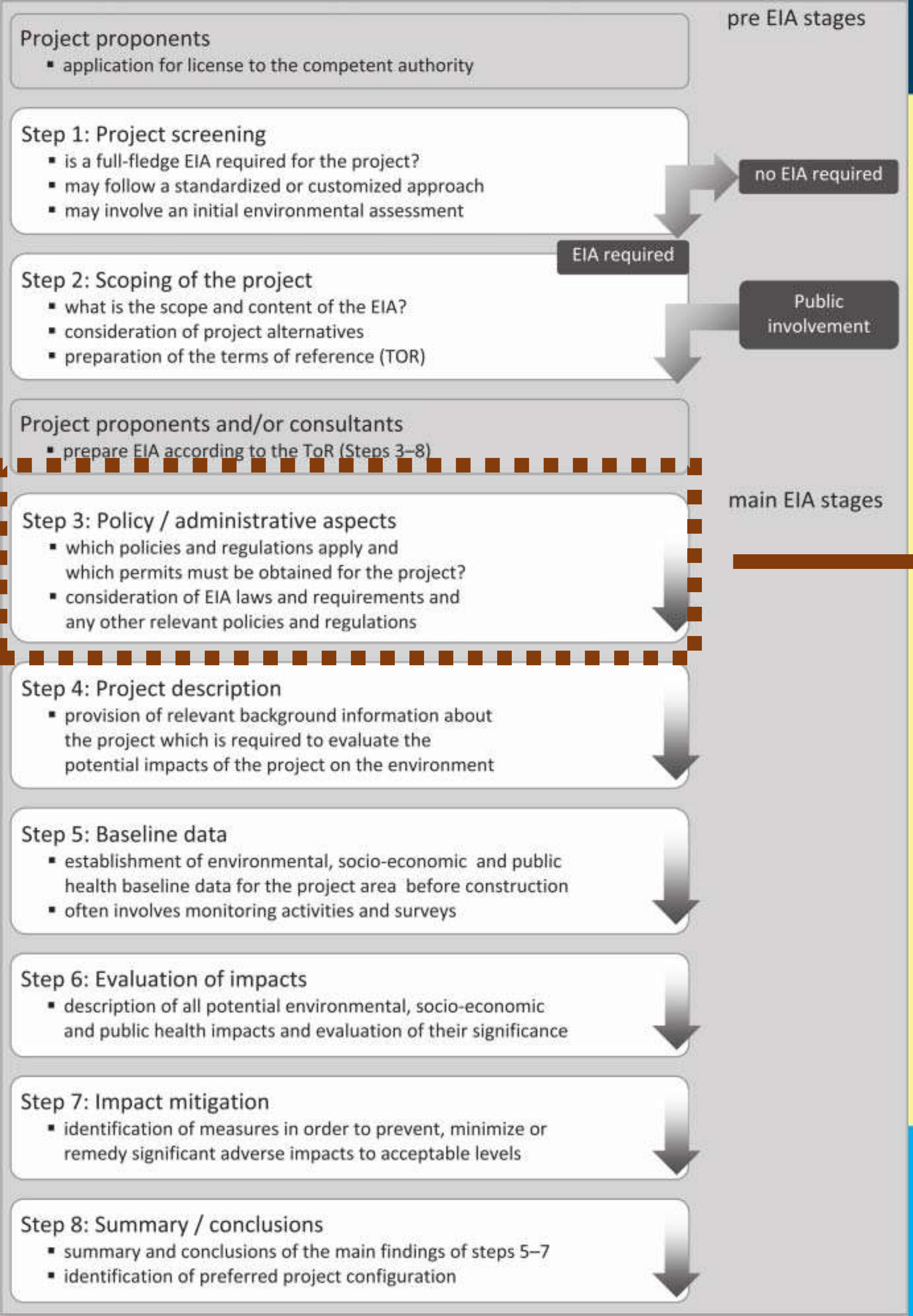
The scoping process identifies the issues that are likely to be of most importance during the EIA and eliminates those that are of little concern. Typically, this process concludes with the establishment of Terms of Reference for the preparation of an EIA.

In this way, scoping ensures that EIA studies are focused on the significant effects and time and money are not wasted on unnecessary investigations.

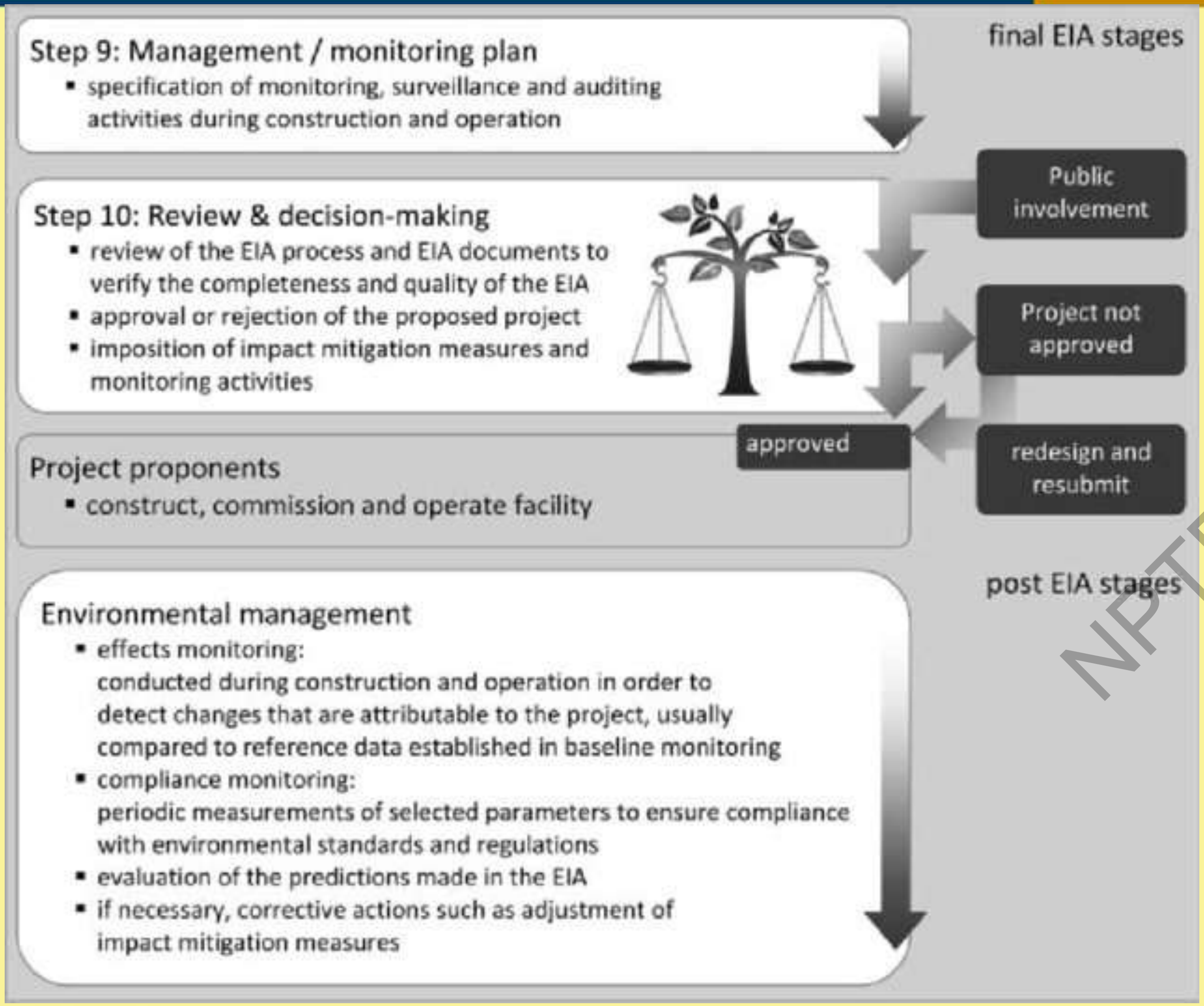
Major issues and impacts that will be important in decision-making on the proposal, and need to be addressed in an EIA

Purpose of scoping is to identify

- The important issues to be considered in an EIA;
- The appropriate time and space boundaries of the EIA study;
- The information necessary for decision-making; and
- The significant effects and factors to be studied in detail.



This seeks to ensure that the proponent has considered other feasible approaches, including alternative project locations, scales, processes, layouts, operating condition and the *no-action* option.


final EIA stages
Step 9: Management / monitoring plan
▪ specification of monitoring, surveillance and auditing activities during construction and operation
Public involvement
Step 10: Review & decision-making
▪ review of the EIA process and EIA documents to verify the completeness and quality of the EIA
▪ approval or rejection of the proposed project
▪ imposition of impact mitigation measures and monitoring activities
Project not approved
approved
redesign and resubmit
Project proponents
▪ construct, commission and operate facility
post EIA stages
Environmental management
▪ effects monitoring:
conducted during construction and operation in order to detect changes that are attributable to the project, usually compared to reference data established in baseline monitoring
▪ compliance monitoring:
periodic measurements of selected parameters to ensure compliance with environmental standards and regulations
▪ evaluation of the predictions made in the EIA
▪ if necessary, corrective actions such as adjustment of impact mitigation measures

Hierarchy in EIA

The EIA studies are broadly categorized as:

- Site selection studies
- Rapid or comprehensive studies
- Regional studies
- Carrying capacity studies

In the last two decades, national governments and also financial institutions have realized that EIA has to be an integral part of the project life cycle: from project conceptualization to post implementation corrective action. Figure illustrates this cycle:

Environmental impact statement (EIS)

The environmental impact statement (EIS) provides documentation of the information and estimates derived from the various steps in the EIA process. The information contained in a EIS provides the decision-makers/regulators with valuable information that could ultimately contribute to either the abandonment or substantial modification of a proposed development action.

Environmental Impact Statement (EIS)

Part 1
Methods and key issues

This part deals with the statement of methods used and a summary of key issues.

Part 2
Background to the proposed development

This part deals with preliminary studies (i.e., need, planning, alternatives, site selection, etc.), site description/baseline conditions, description of proposed development and construction activities and programs.

Part 3
Environmental impact assessments on topic areas

This part deals with land use, landscape and visual quality, geology, topography and soils, hydrology and water quality, air quality and climate, terrestrial and aquatic ecology, noise, transport, socio-economic and interrelationships between effects.

Impact indicators

Good
Better
Best
Acceptable
Unacceptable

AQI categories and breakpoint concentrations with averaging times
(units: µg/m³ unless mentioned otherwise)

AQI Category (Range)	PM_{10} 24-hr	$PM_{2.5}$ 24-hr	NO_2 24-hr	O_3 8-hr	CO 8-hr (mg/m³)	SO_2 24-hr	NH_3 24-hr	Pb 24-hr
Good (0-50)	0-50	0-30	0-40	0-50	0-1.0	0-40	0-200	0-0.5
Satisfactory (51-100)	51-100	31-60	41-80	51-100	1.1-2.0	41-80	201-400	0.6 –1.0
Moderate (101-200)	101-250	61-90	81-180	101-168	2.1- 10	81-380	401-800	1.1-2.0
Poor (201-300)	251-350	91-120	181-280	169-208	10.1-17	381-800	801-1200	2.1-3.0
Very poor (301-400)	351-430	121-250	281-400	209-748*	17.1-34	801-1600	1201-1800	3.1-3.5
Severe (401-500)	430 +	250+	400+	748+*	34+	1600+	1800+	3.5+

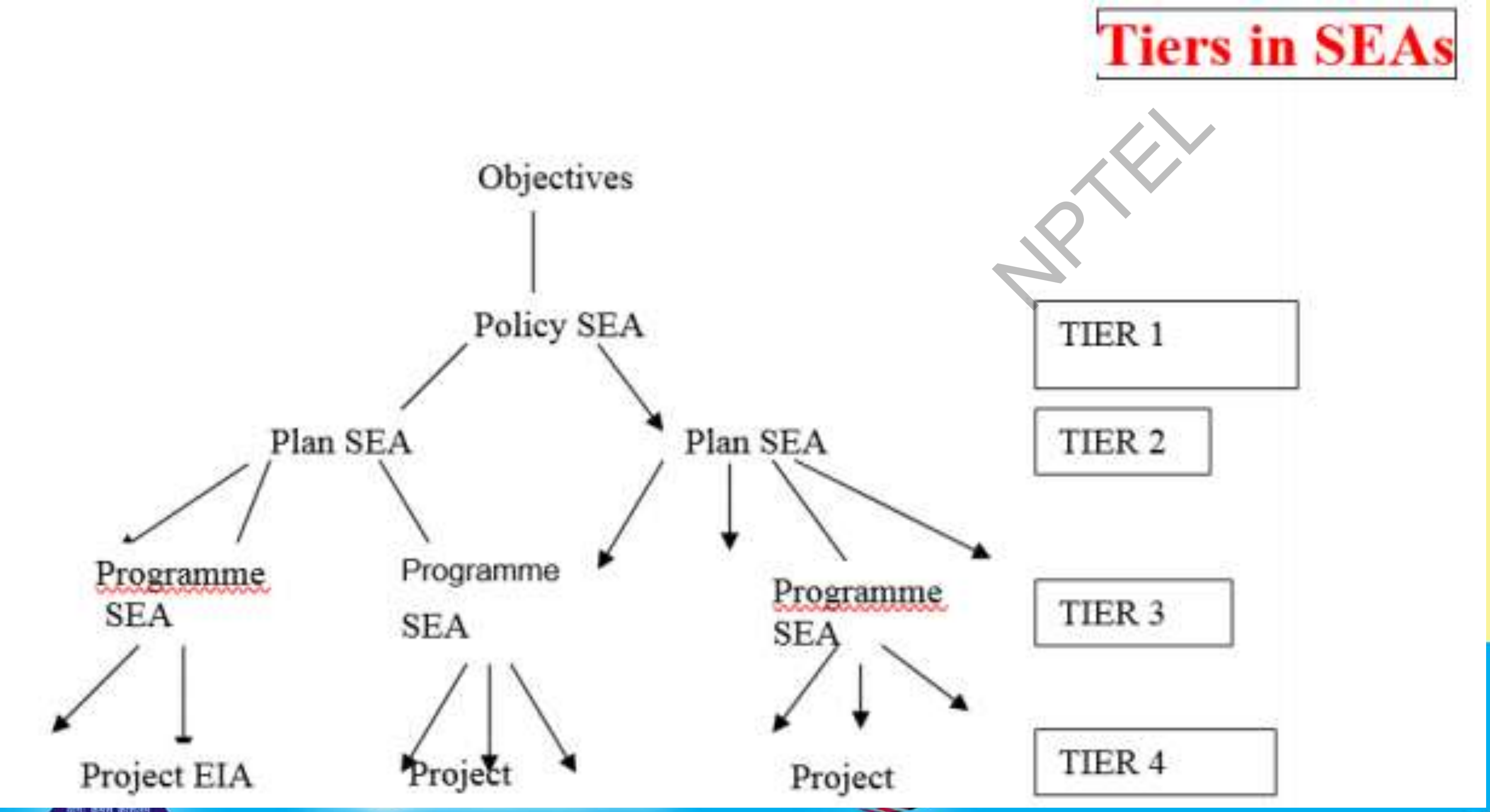
*One hourly monitoring (for mathematical calculation only)

The most widely used impact indicators are those within statutory laws, acts, i.e., indicators such as air and water quality standards that have statutory authority.

Principles of Strategic Environmental Assessment(SEA)

SEA can be defined as "the formalized, systematic and comprehensive process of evaluating the environmental impacts of a policy, plan or programme (PPP) and its alternatives, including the preparation of a written report on the findings of that evaluation, and using the findings in publicly accountable decision-making".

In theory PPPs are tiered; a policy provides a framework for the establishment of plans, plans provide frameworks for programs, and programs lead to projects. The EIA's for these different PPP tiers can themselves be tiered as



Rationale and scope of SEA

The rationale for SEA of policies, plans and programs falls into three main categories

1. Strengthening project EIA and advancing sustainability

- SEA or an equivalent approach can be used as a complement to project-level EIA to incorporate environmental considerations and alternatives directly into policy, plan and program design.

2. Addressing Cumulative and Large Scale Effects

- SEA offers a better opportunity than project-level impact assessment to address cumulative effects.

Rationale and scope of SEA

3. Scope of SEA

- SEA encompasses assessments of both broad policy initiatives and more concrete programs and plans that have physical and spatial references (e.g. town and regional plans, regional development programs.

EIA	SEA
Is usually reactive to a development proposal	Is pro-active and informs development proposals
Assesses the effect of a proposed development on the environment.	Assesses the effect of a policy, plan or program on the environment, or the effect of the environment on development needs and opportunities.
Addresses a specific project	Addresses areas, regions or sectors of development.
Assesses direct impacts and benefits.	Assesses cumulative impacts and identifies Implications and issues for sustainable development
Focuses on the mitigation of impacts	Focuses on maintaining a chosen level of Environmental quality.
Narrow perspective and a high level of detail.	Wide perspective and a low level of detail to provide a vision and overall framework.
Focuses on project-specific impacts.	Creates a framework against which impacts and benefits can be measured

Environmental Clearance Procedure in India

The EIA process in India is made up of the following phases:

- ✓ Screening;
- ✓ Scoping and consideration of alternatives;
- ✓ Baseline data collection impact prediction;
- ✓ Assessment of alternatives, delineation of mitigation measures and environmental impact statement;
- ✓ Public hearing Environment Management Plan;
- ✓ Decision making;
- ✓ Monitoring the clearance conditions.

The Ministry of Environment and Forests (MoEF) has published guidelines for different sectors.

The following documents need to be submitted for project clearance

1. Filled in Application Form (as per Schedule II of EIA Notification)
2. A summary of the project/feasibility report (I copy)
3. EIA (EIS)/EMP report (20 copies)
4. Risk Analysis on on-site Emergency Preparedness Plan (20 copies) in case of projects involving hazardous substances
5. Site clearance from MOEF for site-specific projects mentioned in the EIA Notification
6. Consent to Establish from SPCB
7. NOC from the local authorities (e.g. District Collector)
8. Commitment regarding availability of water and electricity from the appropriate agencies
9. Approval of the Chief Controller of Explosives under the Petroleum Act and Rules for layout and storage of hazardous substances and from the Directorate of Industrial Safety and Health under the Factories Act and Rules
10. Comments/Observations/Recommendations of the Chief Wildlife Warden in case a wildlife habitat/migration path exists within 25 km of project site
11. Comprehensive (if more than 1,000 people are likely to be displaced) / Summary Rehabilitation Plan where displacement of people is anticipated
12. Copy of the application forwarded to the state government, in case of diversion of forest land
13. Copy of the application forwarded to the state government in case the CRZ Notification applies
14. Clearance from the Airport Authority of India, if applicable

The following documents need to be submitted for project clearance

15. Details of the public hearing conducted by SPCB/Copy of the advertisements issued for public hearing
16. Filled-in Environmental Appraisal Questionnaires issued by MOEF, along with the attachments (mentioned in the questionnaire)

- Bonafide local residents;
- Local associations;
- Environmental groups: active in the area;
- Any other person located at the project site / sites of displacement.

17. The Impact Assessment Agency (IAA) evaluates and assesses the EIA report.
18. Environmental clearance conditions and recommendations of IAA are made available to the public on request.

Environmental Clearance Process

Categorization of projects and activities:- All projects and activities are broadly categorized in to two categories based on the spatial extent of potential impacts and potential impacts on human health and natural and man made resources.

Category 'A'	Category 'B'
Prior environmental clearance from MoEF on recommendations of an Expert Appraisal Committee (EAC) to be constituted by the Central Government	Prior environmental clearance from the State/Union territory Environment Impact Assessment Authority (SEIAA) on recommendations of a State or Union territory level Expert Appraisal Committee (SEAC). In the absence of a duly constituted SEIAA or SEAC, a Category 'B' project shall be treated as a Category 'A' project;

Source: http://moef.nic.in/legis/eia/so1533.pdf

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Lecture 29: LCA

Design and Sustainability

- The things that we design, create, and consume contribute SUBSTANTIALLY to our environmental impacts
- Common terms
  - Sustainable Engineering
  - Sustainable Design
  - Design for the Environment
- Move beyond carbon footprint or water footprint

Environmental Considerations and Design

- Key consideration of any design
- It must be addressed!
- Life Cycle Analysis (LCA) is connected to environmental consideration

Can engineers fundamentally change the environmental footprint of modernity?

- Yes – engineers need tools to identify "better" design options
- No – what are we doing here? What use are we

then?

Two levers in the design engineers' hand

1. Material and resource inputs – keep to minimum

Way too much packaging?

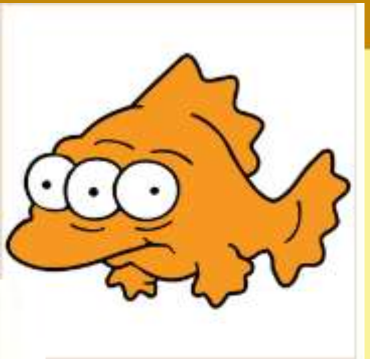
Two levers in the design engineers' hand

1. Material and resource inputs – keep to minimum
2. As designers - we can make better decisions about what we are designing
    - Design for disassembly
    - Design for maintainability
    - Design for longevity

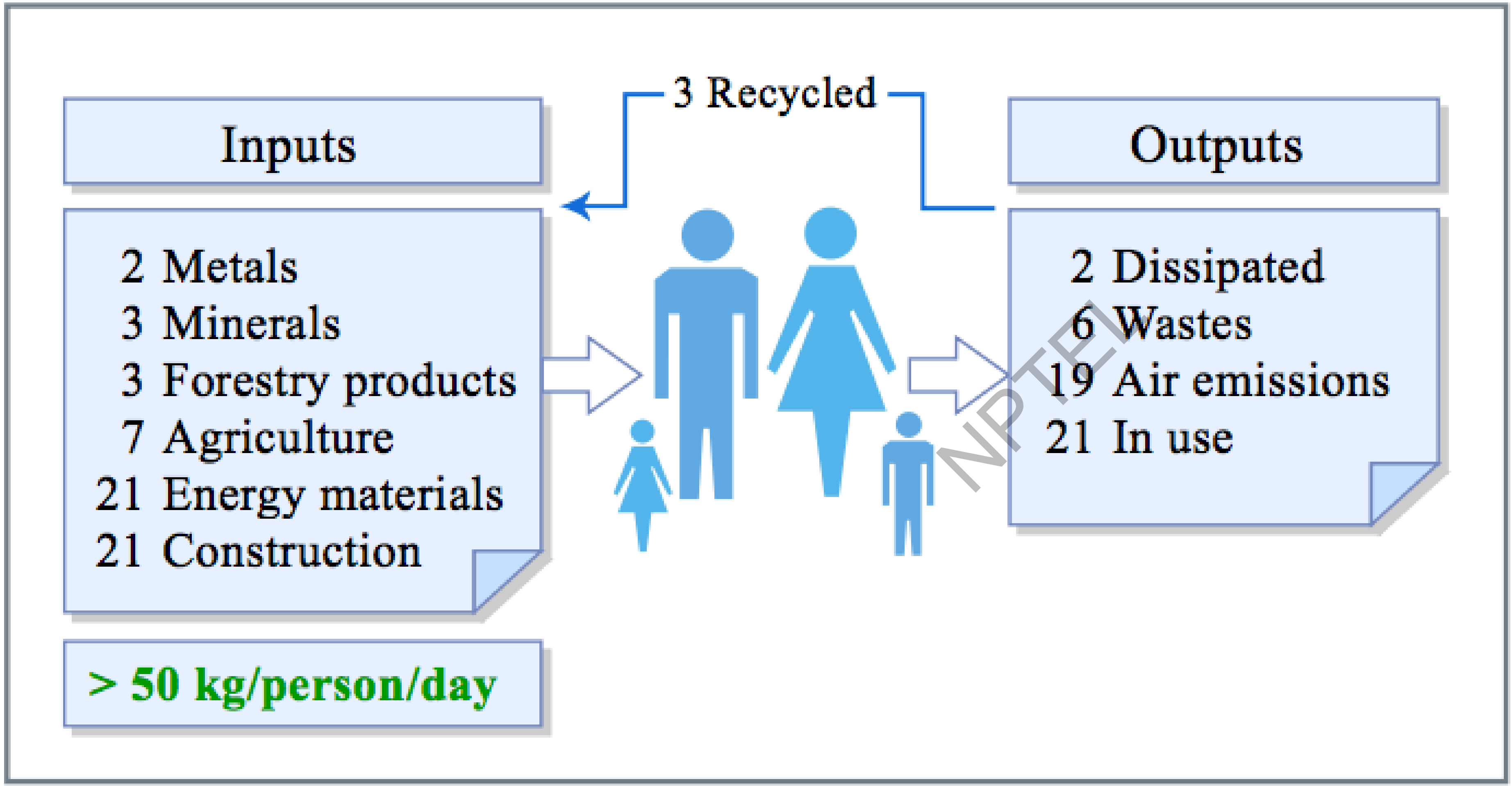
Why should we care?

- What catastrophe do you want to talk about?
  - Rising ocean levels
  - Ozone hole
  - Greenhouse gases
  - Ocean plastic
  - Soil fertility and food supplies
  - Water supplies

Don’t eat the fish!



How much do you use per day?



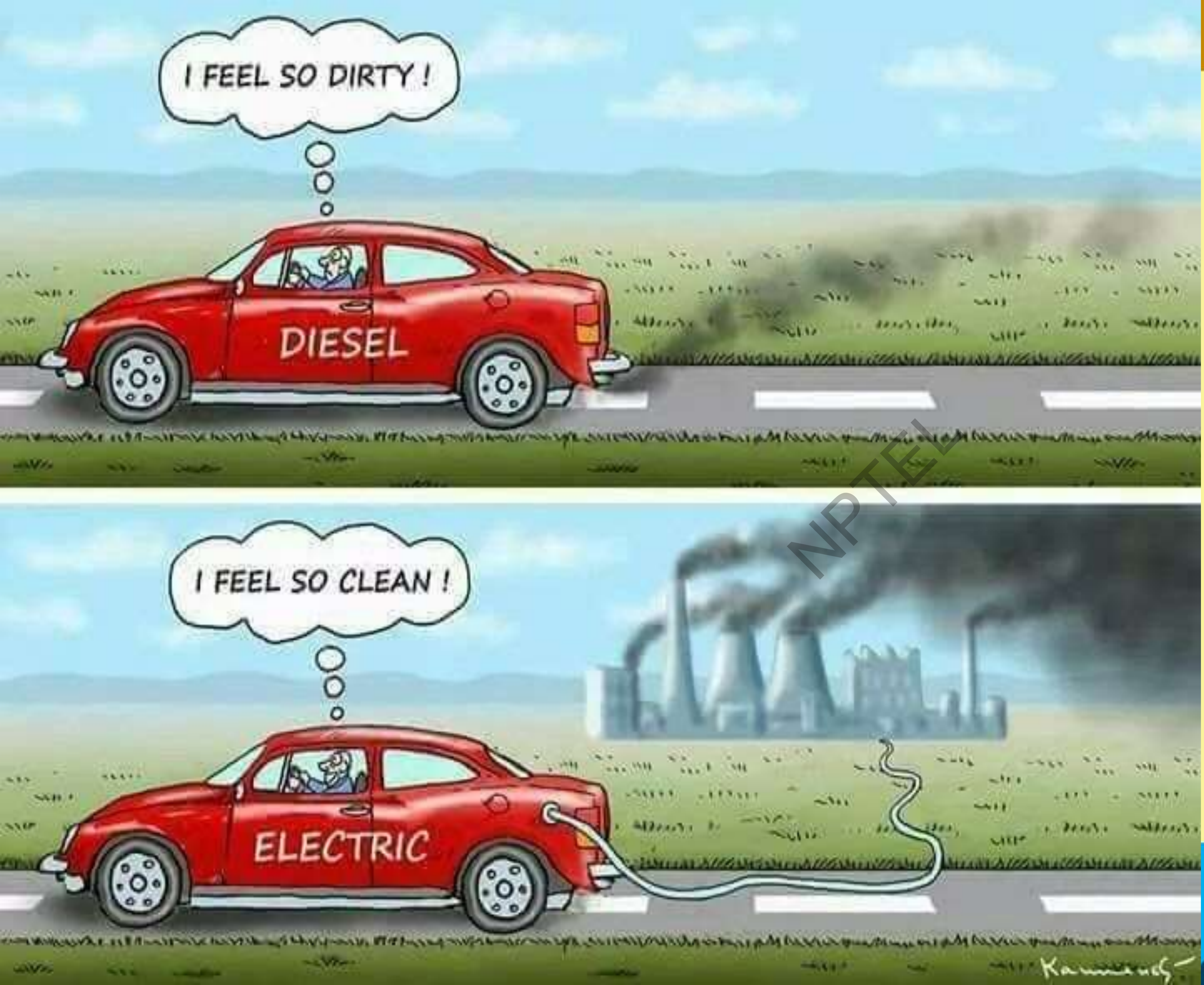
- Burtynski

We can do better

Sustainable development meets the needs of the present **without compromising** the ability of future generations to meet their own needs.

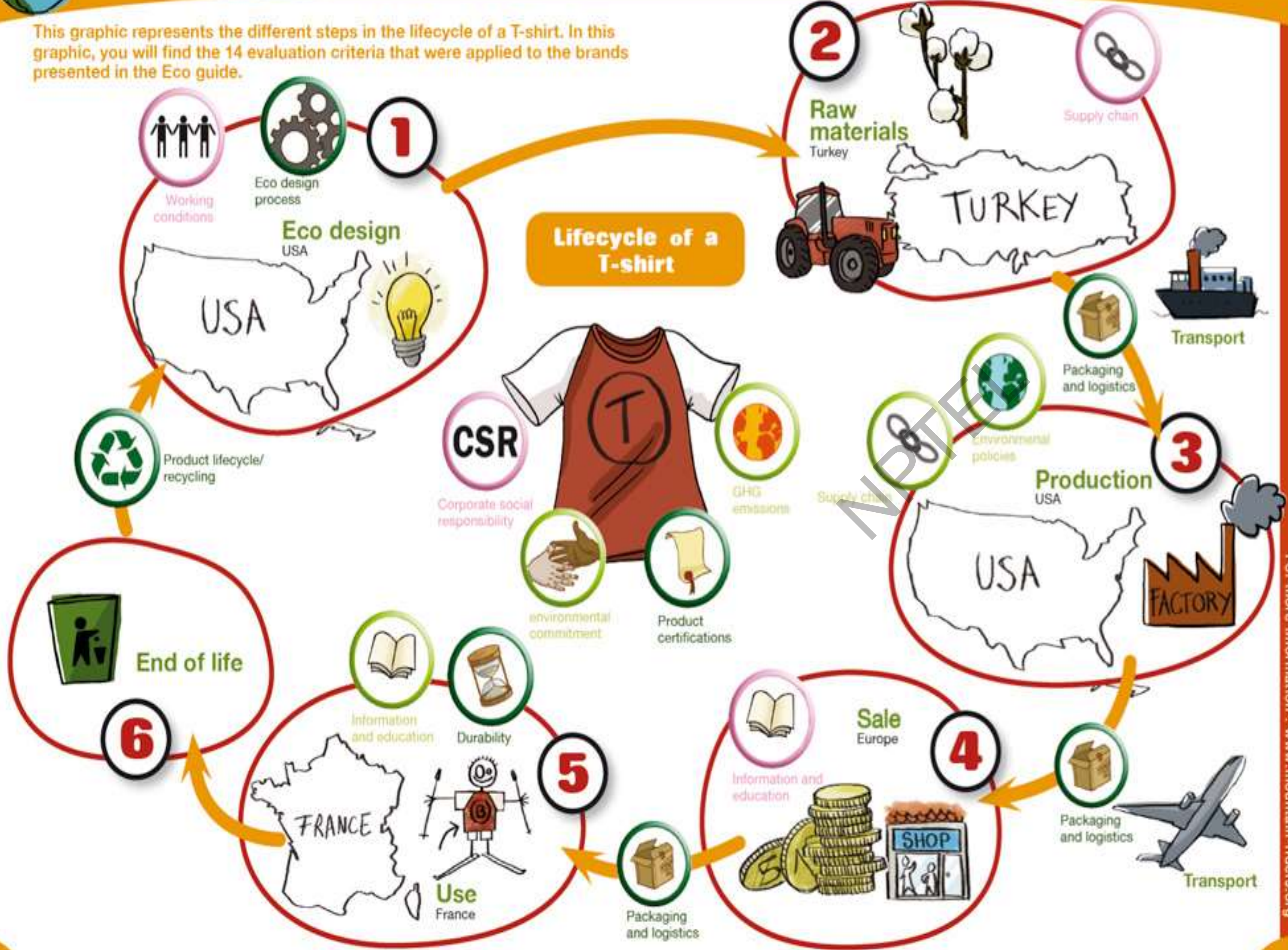
Life Cycle Thinking

- Thinking about the the many consequences of a product or process over its entire life cycle
  1. Concept
  2. Materials and Material Extraction
  3. Manufacturing and Packaging
  4. Transportation
  5. Retail/Use (Don’t forget cleaning)
  6. Disposal – Landfill or incineration
  7. Recycling


I FEEL SO DIRTY !
DIESEL
I FEEL SO CLEAN !
ELECTRIC

From the cradle to the grave

This graphic represents the different steps in the lifecycle of a T-shirt. In this graphic, you will find the 14 evaluation criteria that were applied to the brands presented in the Eco guide.



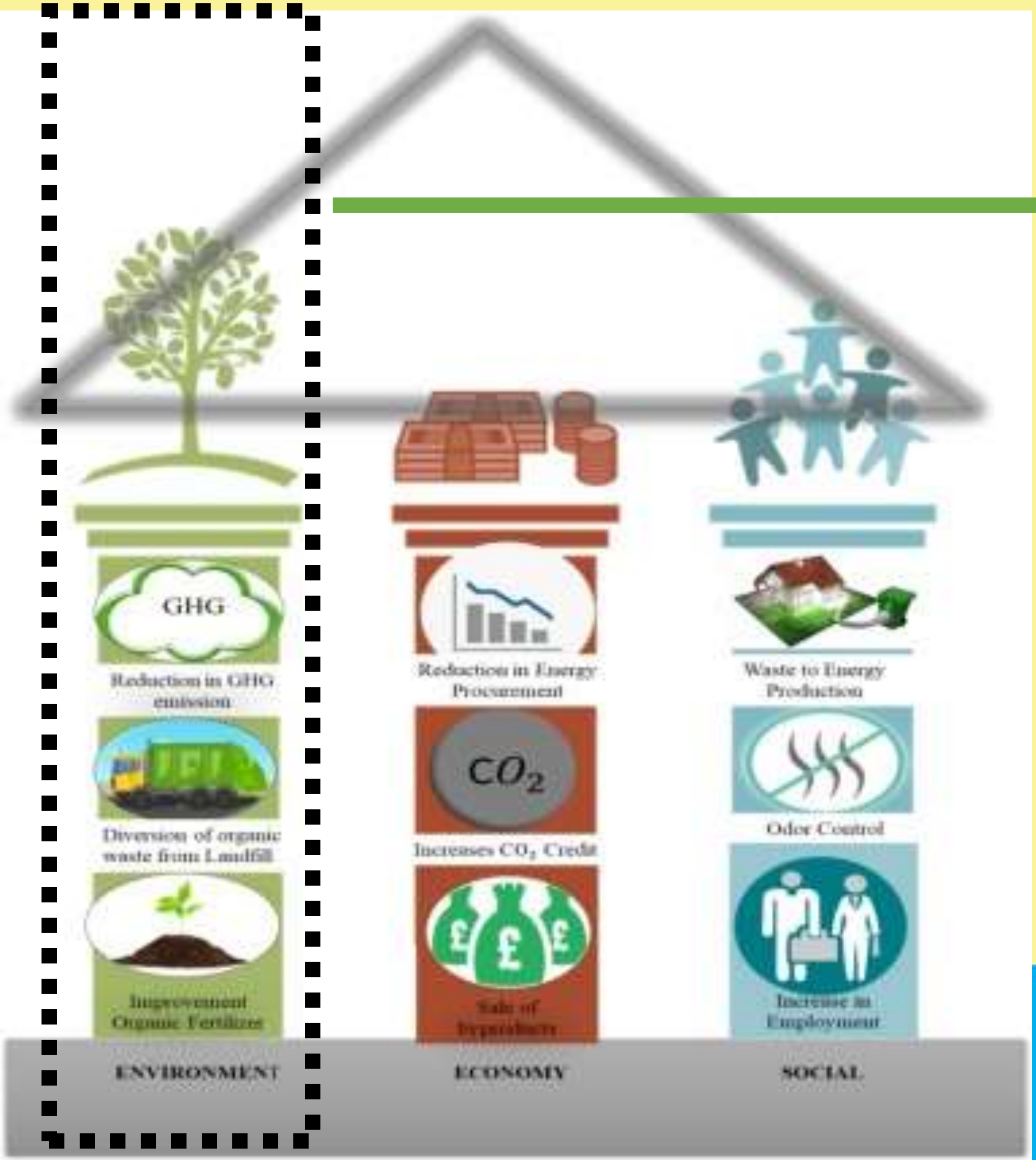
Environmental Folklore

- The assumptions we make about what's green and what's not
- Usually based on our experiences, up bringing, media, education ….
- Often not based on scientific understanding
- Often leads to impact transfer not impact reduction
- The fluffy feel-good feeling we get about what's 'green'

Life Cycle Assessment

- Systems thinking and complexity
- a scientific process - governed by ISO 14040, ISO 14043
- "a technique for assessing the environmental aspects and potential impacts associated with a product, system or service." -ISO 14040

What is sustainable?

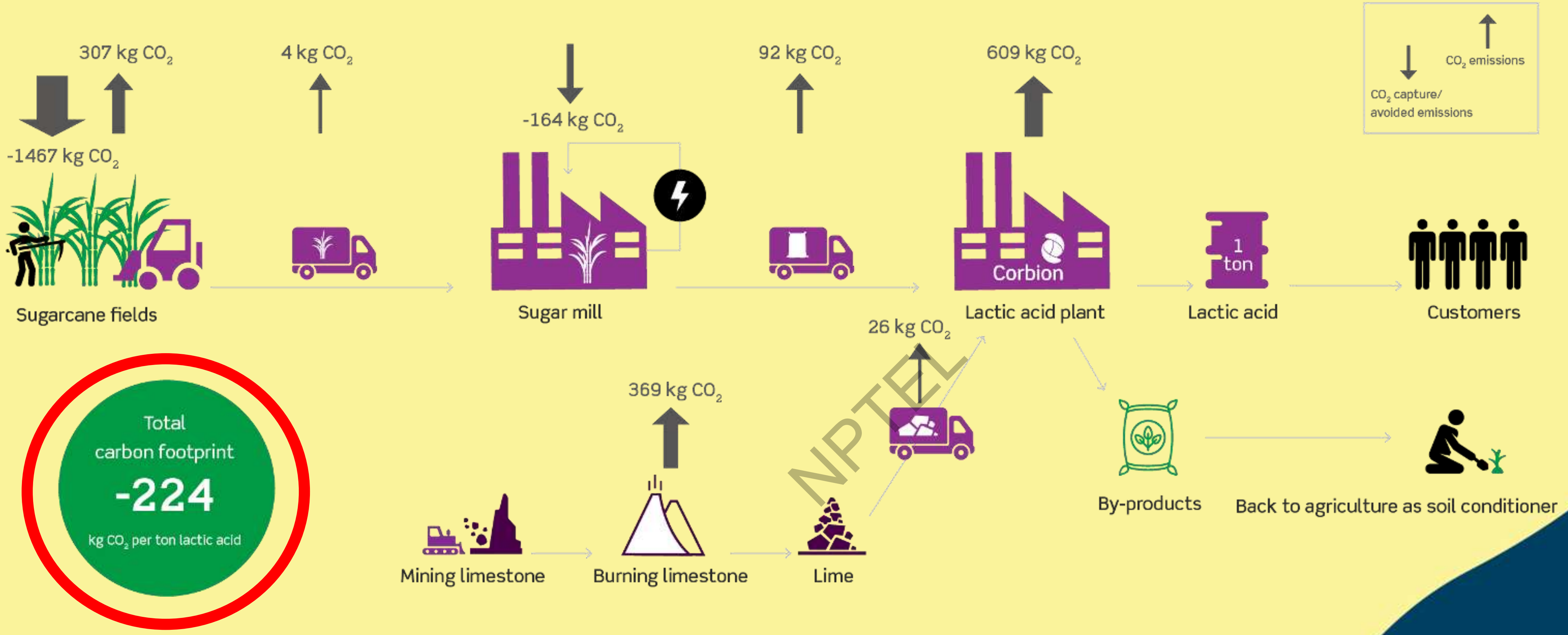


Life Cycle Assessment

Life Cycle Assessment

Definition:

“Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle”



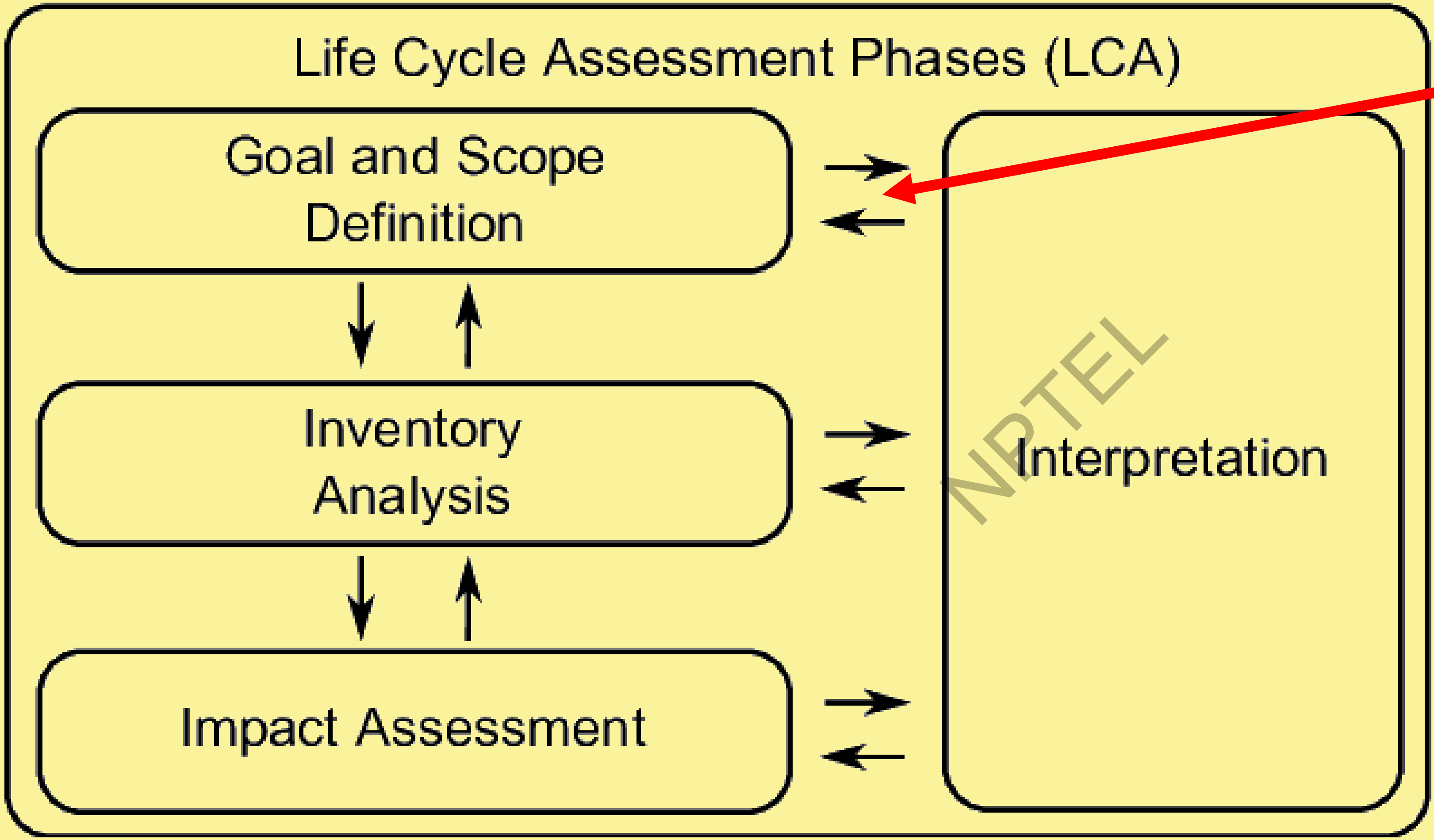
Source: Holmatov, B., Hoekstra, A. Y., & Krol, M. S. (2019). Land, water and carbon footprints of circular bioenergy production systems. *Renewable and Sustainable Energy Reviews*, *111*, 224-235.

LCA study consist of 4 steps

- Define goal and scope
- Life cycle inventory stage - all environmental input and output
- Life cycle impact assessment – understanding the environmental relevance of all the inputs and outputs
- The interpretation of the study

What Makes Up LCA?

Source: ISO 14040



Why this arrow?

The phases are iterative nature

Goal & Scope Definition

What is the purpose of the LCA and who is the audience?

Inventory Analysis (LCI)

1. What is the function & functional unit?
2. Where are the boundaries?
3. What data do you need?
4. What assumptions are you making?
5. Are there any limitations?

Impact Assessment (LCIA)

What are the environmental, social, and economic affects?

Interpretation

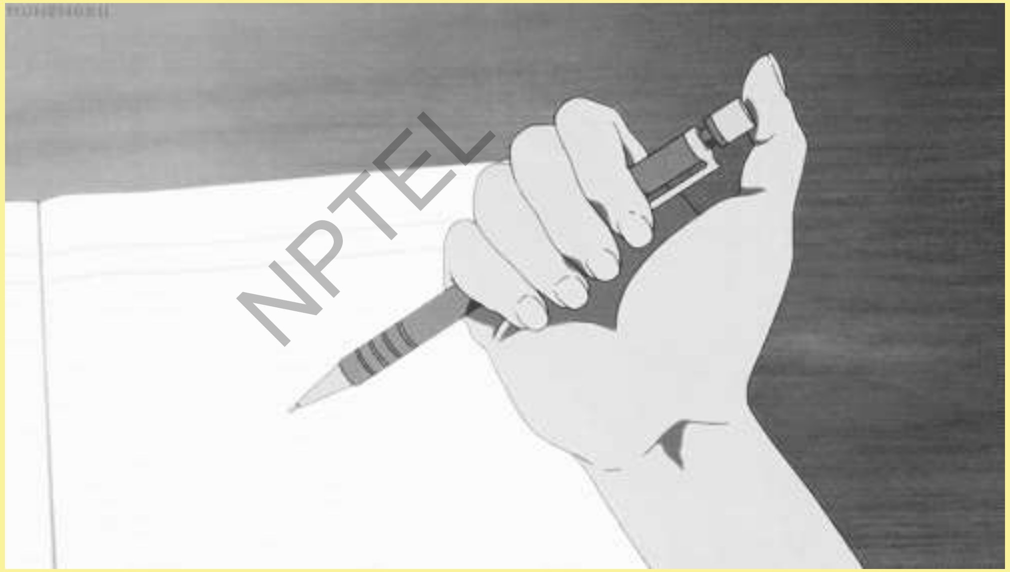
Ways to reduce environmental impacts.

What conclusions can you draw from the study?

What recommendations can be made?

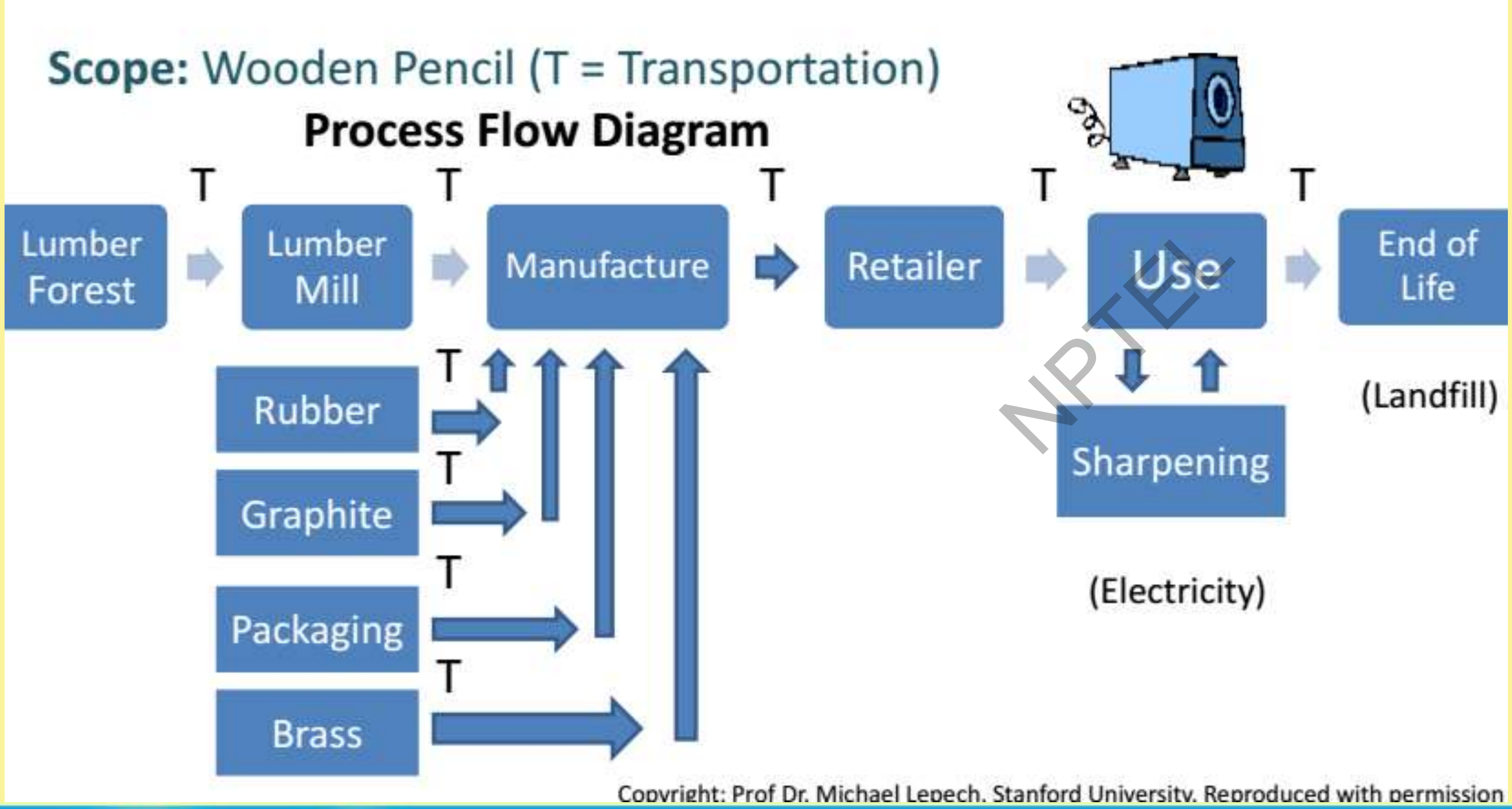
Goal and Scope

Wooden Pencil vs. Mechanical Pencil



Goal and Scope

Wooden Pencil

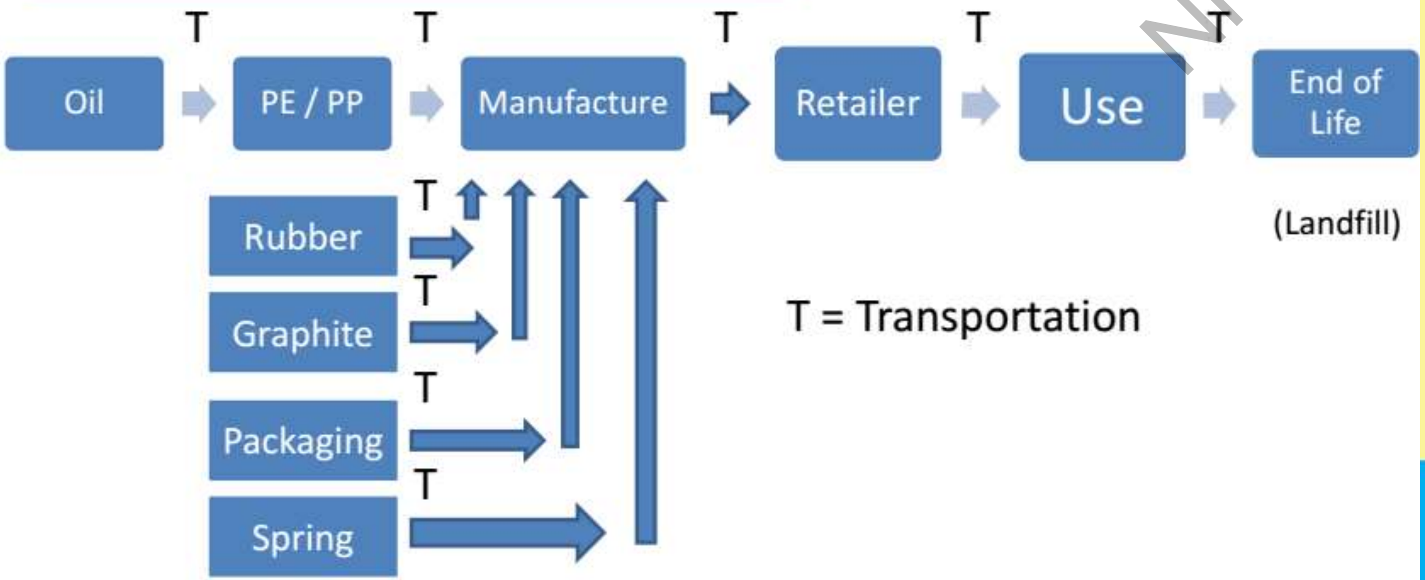


Goal and Scope

Mechanical Pencil

Scope: Mechanical Pencil

PE = Polyethylene
PP = Polypropylene
Both materials are **plastic polymers** (large molecules) used to make many products.



Function & Functional Unit

Function

- Service provided by a system
- What it does!

Functional Unit

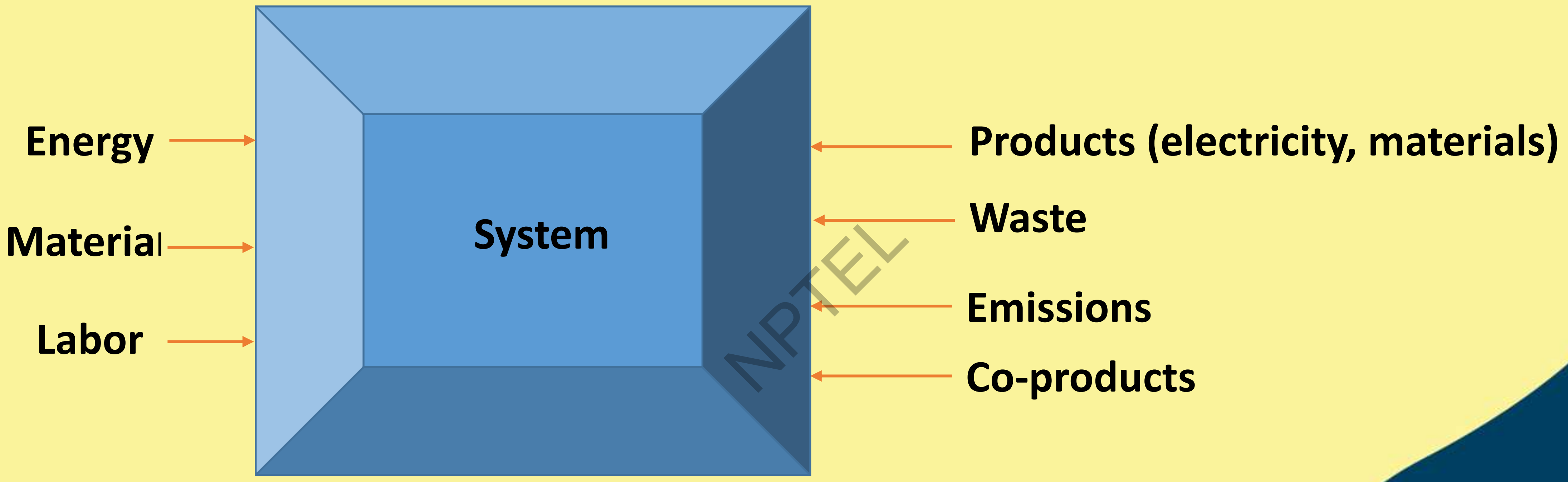
- Gives the function a number value
- Allows comparison between products
- Reference point

Example

Wooden Pencil vs. Mechanical Pencil

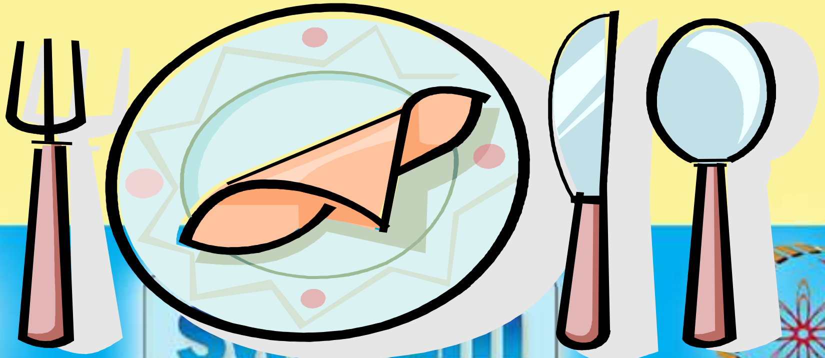
- Function = “Writing”
- Functional Unit = “1 meter of writing”

Items To Consider??



LCA in Action: Think About It!
Paper Plate vs. China (Plate You Wash & Reuse)

- ✓ What is the function?
- ✓ What is the functional unit?
- ✓ What materials & resources are used?
- ✓ What does it take to produce both?



- ✓ What are the impacts to the environment?
- ✓ Is there waste?
- ✓ Does washing the China produce waste?
- ✓ What types of data do you need?
- ✓ How do you know which is better?

Data Analysis
Environmental Impact Categories

Global Warming Potential

- Gases in the atmosphere that absorb and emit radiation
- Trap heat from the sun
- Water vapor, CO_2 , CH_4 , ozone, NO_2

Abiotic Depletion

- Consumption of non-living resources

Human Toxicity Potential

- Value that shows harms to humans from chemicals

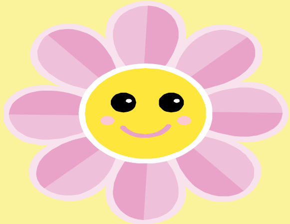
Land Use

- How much land is needed

Let's look at another example

Where Do We Go From Here?

- What is the purpose of all this data??
- Scientists can make recommendations of choices that are less impactful
- Scientists can analyze a particular impact and focus on a solution
- Industry & Individuals can take a closer look at how they can make a difference



Environmental Impact Categories Continued . . . . .

Eutrophication

- Increase in chemical nutrients containing nitrogen or phosphorus
- Land or water
- Overgrowth of plants
- Killing organisms at bottom of water

Water Use

Mercury

Acidification

- Caused by pollution from fuels & acid rain
- Low pH

Smog (Winter or Summer)

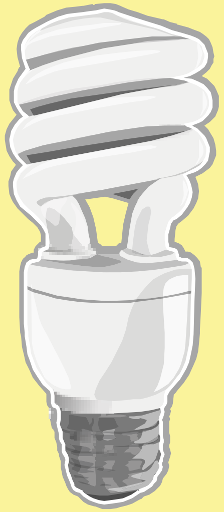
Energy Use

Solid Waste

Oil

. . . . AND MANY MORE!!

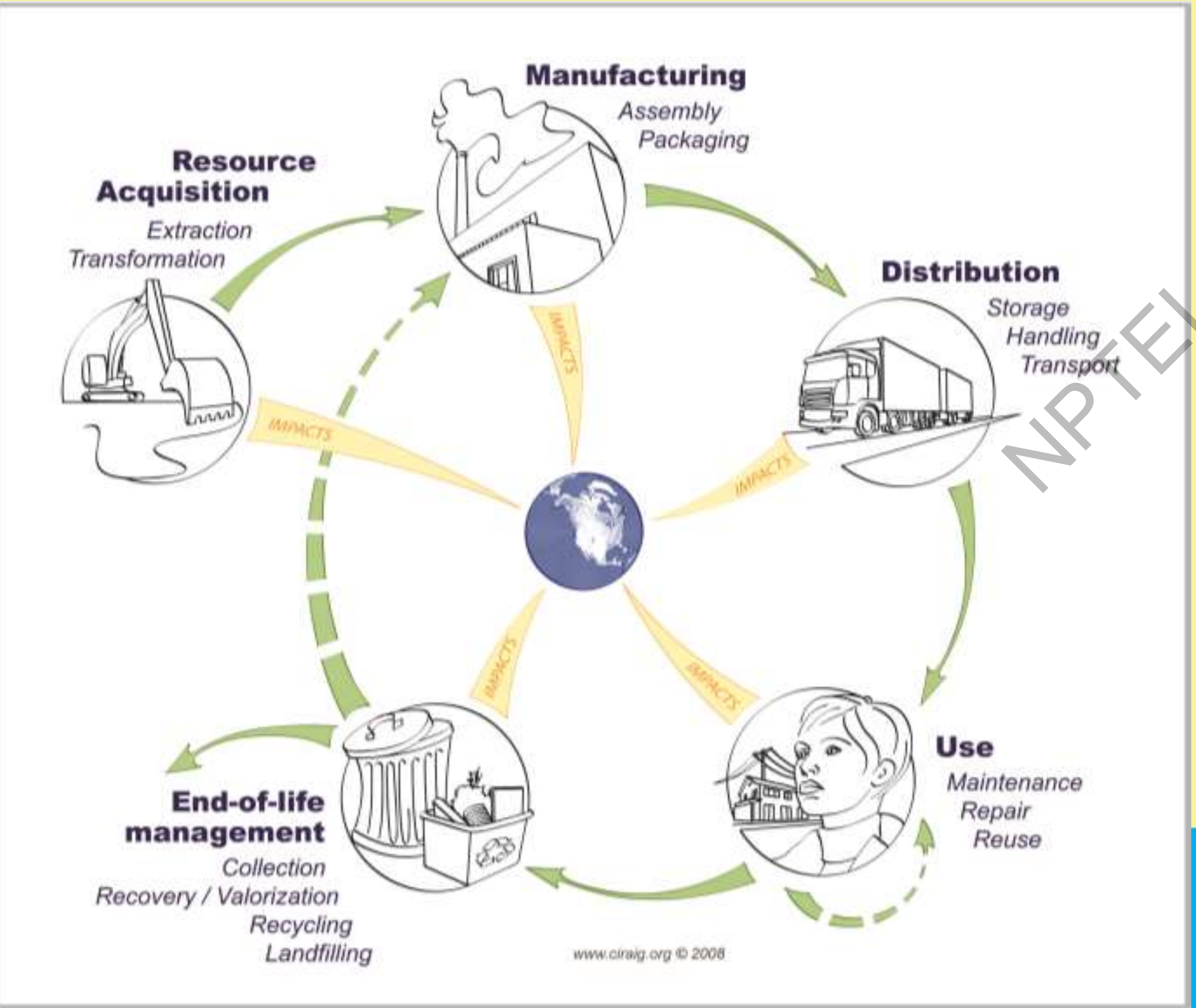
Comparaison of light bulbs



Compact fluorescent	Incandescent

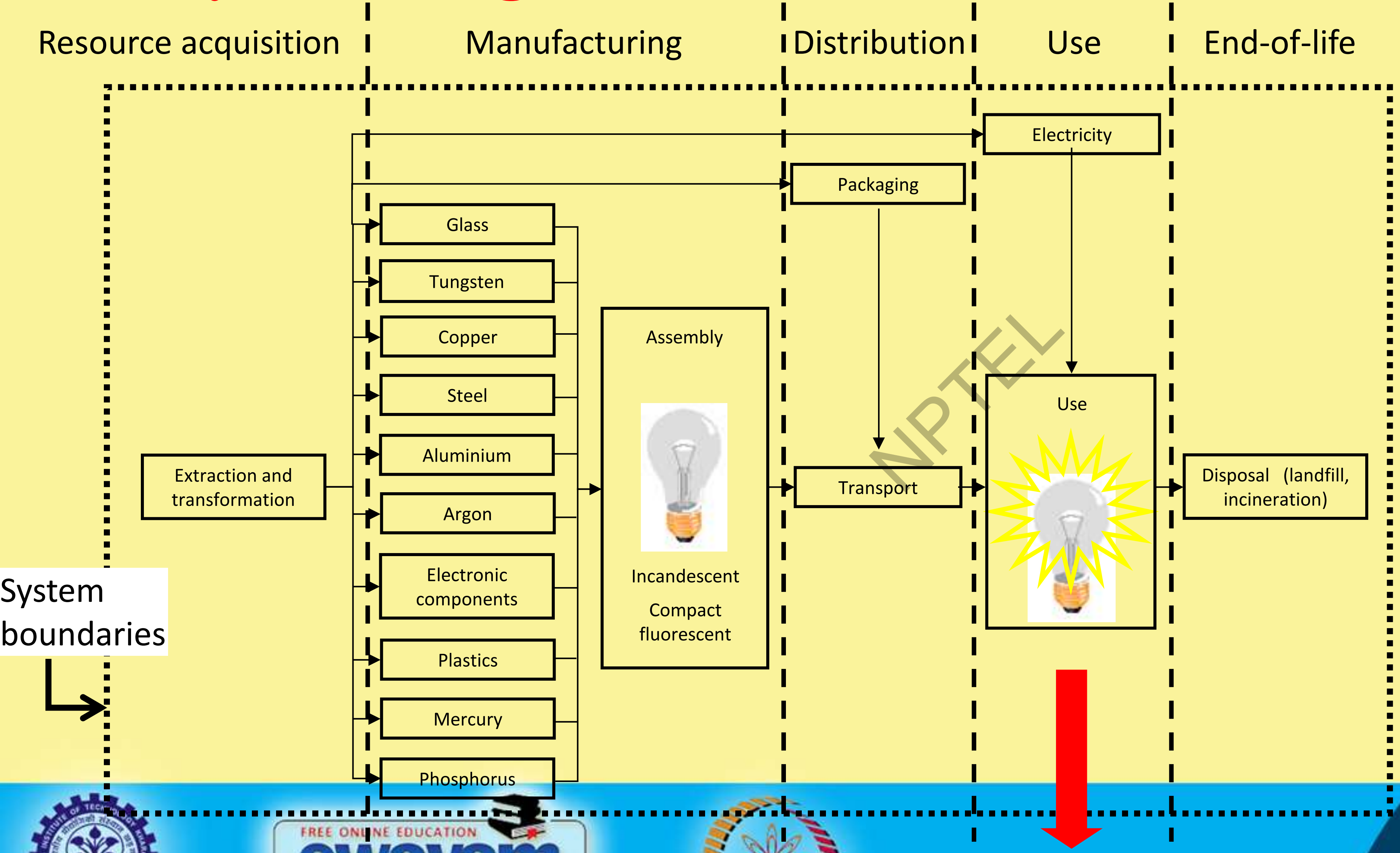
Compact fluorescent light bulb is worse, equal or better?

The life cycle of a product



All processes associated with the product, **wherever** and **whenever** they might occur

Life cycle of a light bulb



Bulb's function = Lighting

LCA = An accounting exercise

Environmental impacts	=	Perturbations of natural cycles by environmental interventions
Environmental intervention	=	Change in state of natural environment due to human activities
LCA	=	Accounting for all environmental interventions associated with life cycle of product

Life cycle inventory

Inputs

Natural resource extractions

Iron ore
Crude oil
Water
Wood
Solar energy
Land use

Resource Acquisition

Manufacturing

Distribution

Use

End-of-Life

Outputs

Emissions in

Air : CO_2, SO_2, PM, VOC
Water : PO_4, NO_3
Soil : pesticides, metals

Other environmental interventions

Radiations
Heat
Noise

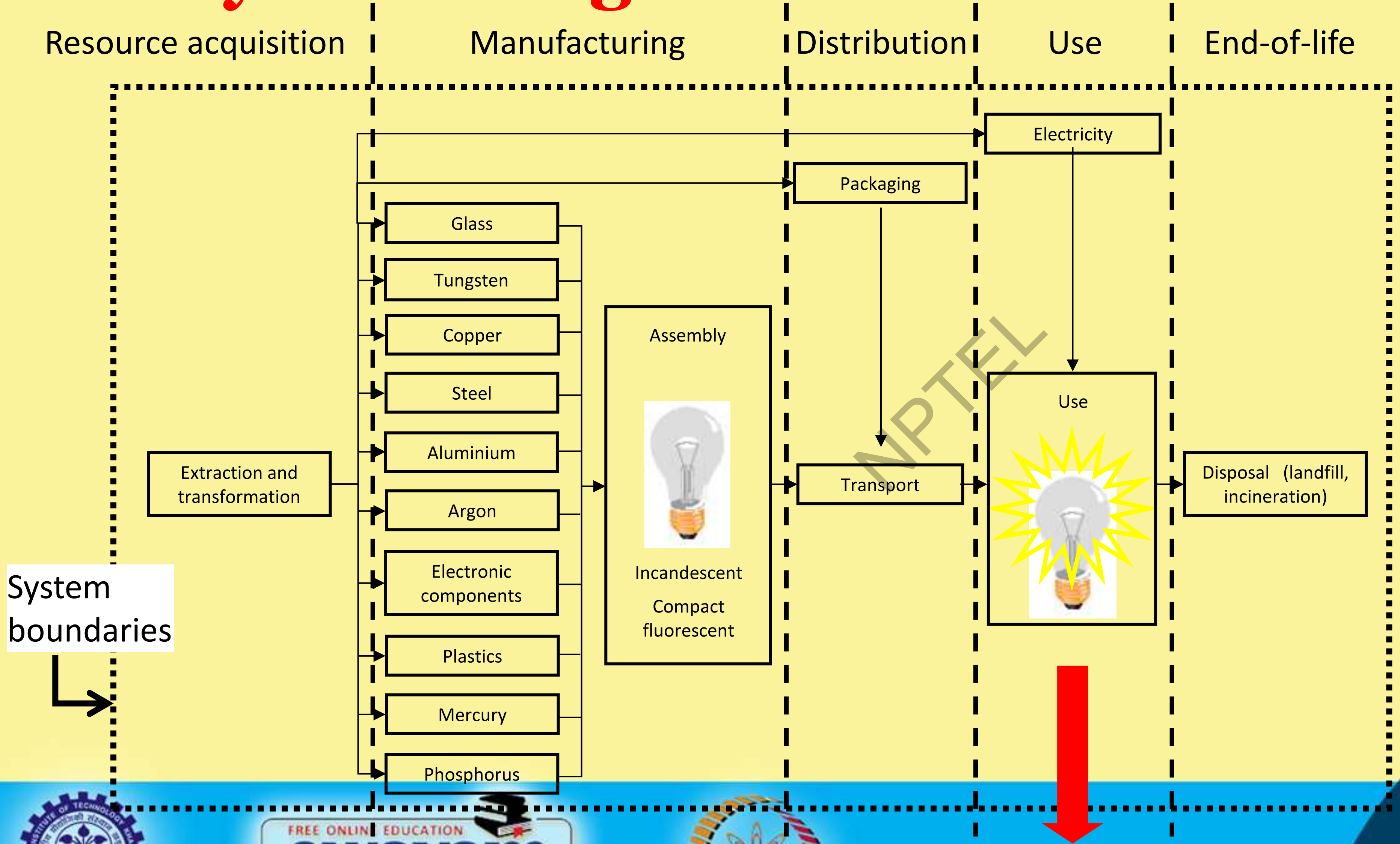
Functional unit

= given « amount » of function to which all inputs and outputs are related to

Functional unit and reference flow

- Product comparison is the functional unit or comparison basis
- In many cases, one cannot simply compare product A and B, as they may have different performance
- For example, comparing milk cartoon and a returnable milk bottle (can be used many times)
- May be comparing two ways of packaging and delivering 1000 litres of milk is a better option

Life cycle of a light bulb



Bulb's function = Lighting

Defining the functional unit

Products	Primary function	Secondary functions
Incandescent light bulb	Lighting	Heating Creating an ambiance
Compact fluorescent light bulb		

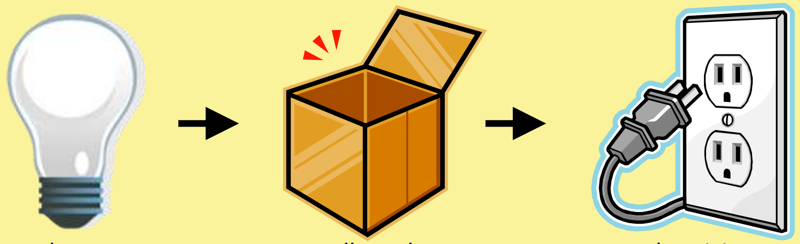
Products	Functional unit = « service provided »	Reference flows = « what is needed »	Key parameters
Incandescent light bulb	Providing 700 lumens	10 bulbs 600 kWh of electricity	Lifetime Watt/lumen ratio
Compact fluorescent light bulb		1 bulb 14 kWh of electricity	

Inventory for a light bulb

1° Product system

(modeled by analyst)

Lighting needs :



2° Functional unit (FU)

Providing 700 lumens for 10000 hours

3° Referece flows

(data collected by analyst)

Providing 700 lumens for 10000 hours needs :

228 g glass	232 g cardboard	600 kWh

4° Unit processes

(measured, calculated or estimated data, specific (primary) or generic (secondary) data)

	For 1 kg glass	For 1 kg cardboard	For 1 kWh
Inputs	94 g crude oil 1.0 g iron ore 1300 l water	77 g crude oil 16 g iron ore 3200 l water	1.3 g crude oil 0.29 g iron ore 19000 l water
Outputs	0.52 kg CO2 0.26 g PM2.5 1.6 mg benzene	1.1 kg CO2 0.32 g de PM2.5 8.7 mg benzene	23 g CO2 5.8 mg de PM2.5 0.61 mg benzene

5° Elementary flows inventory

	Per FU	Per FU	Per IFU
Inputs	21 g crude oil 0.23 g iron ore 300 l water	18 g crude oil 3.7 g iron ore 740 l water	780 g crude oil 170 g iron ore 11 000 000 l water
Outputs	0.11 kg CO2 59 mg PM2.5 0.36 mg benzene	0.26 kg CO2 74 mg PM2.5 2.0 mg benzene	14 kg CO2 3.5 g PM2.5 370 g benzene

Life cycle inventory

Elementary flows

Inputs:

Iron ore
Crude oil
Water
Wood
Solar energy
Land use
…

Outputs :

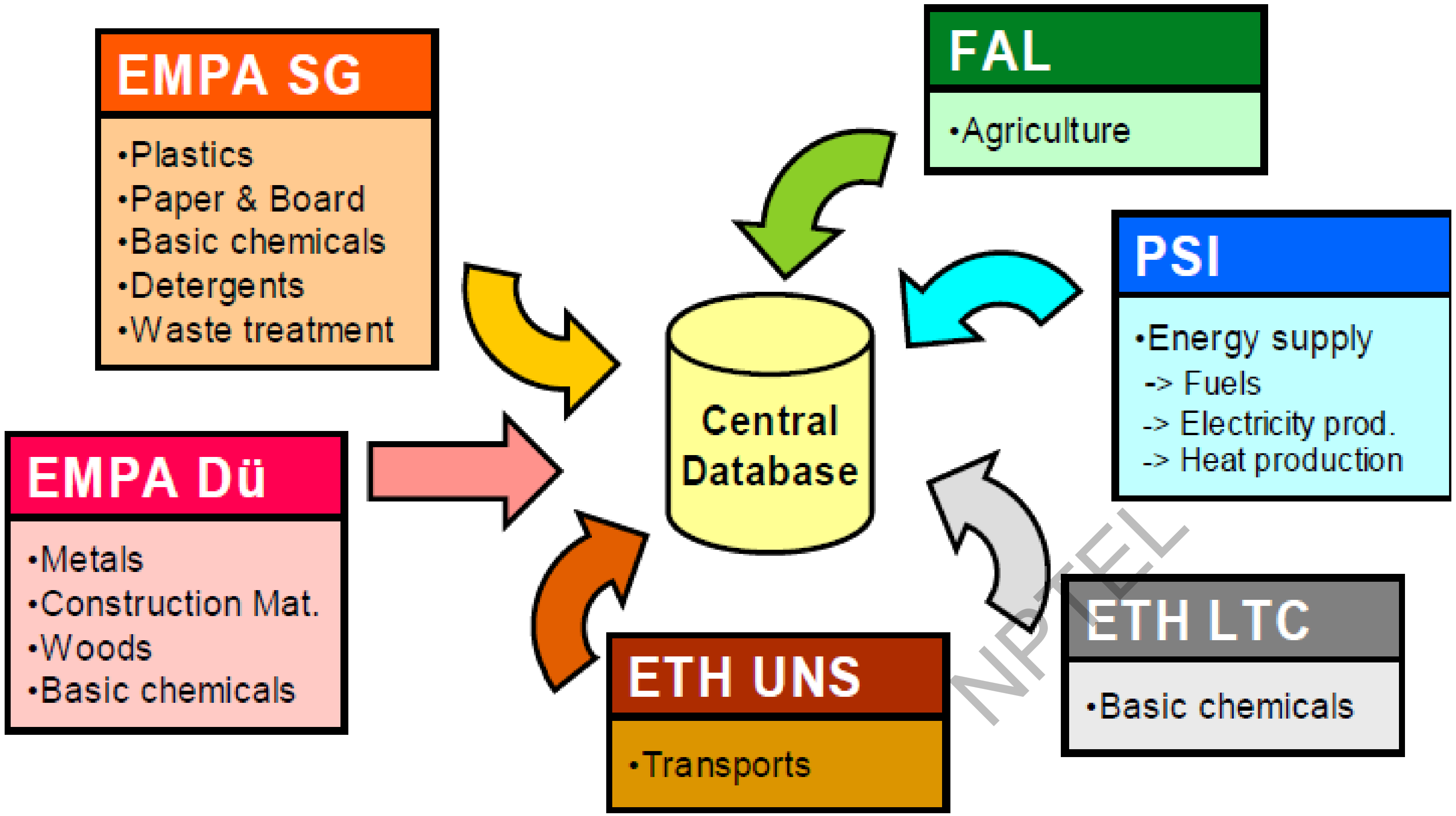
CO_2
SO_2
PM
VOC
PO_4
NO_3
Pesticides
Metals
…

Inventory may count hundreds of different elementary flows

➔ Very hard to interpret

➔ Brain can simultaneously consider only up to 7 independent parameters

Neglecting processes in the process tree which contributes to less than 0.1% of environmental load



The figure above shows the Swiss organisations that joined forces to create the Ecoinvent database. See www.ecoinvent.org for more information.

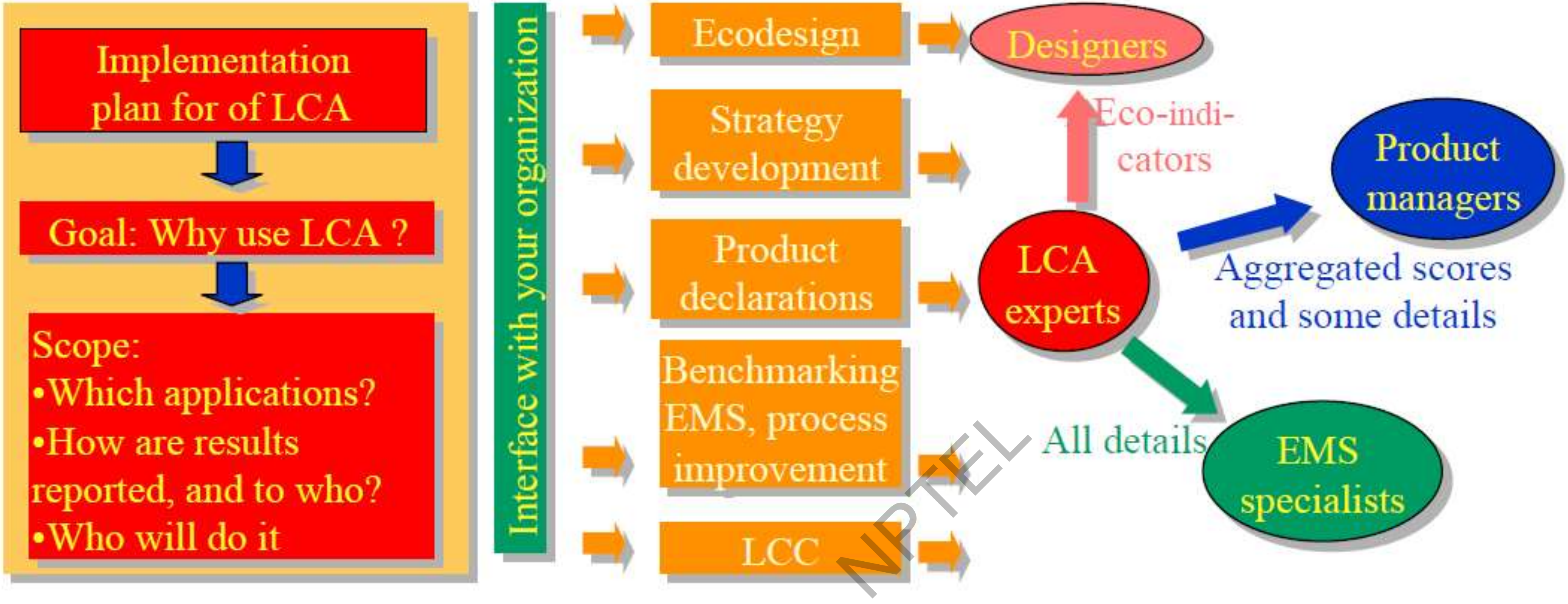
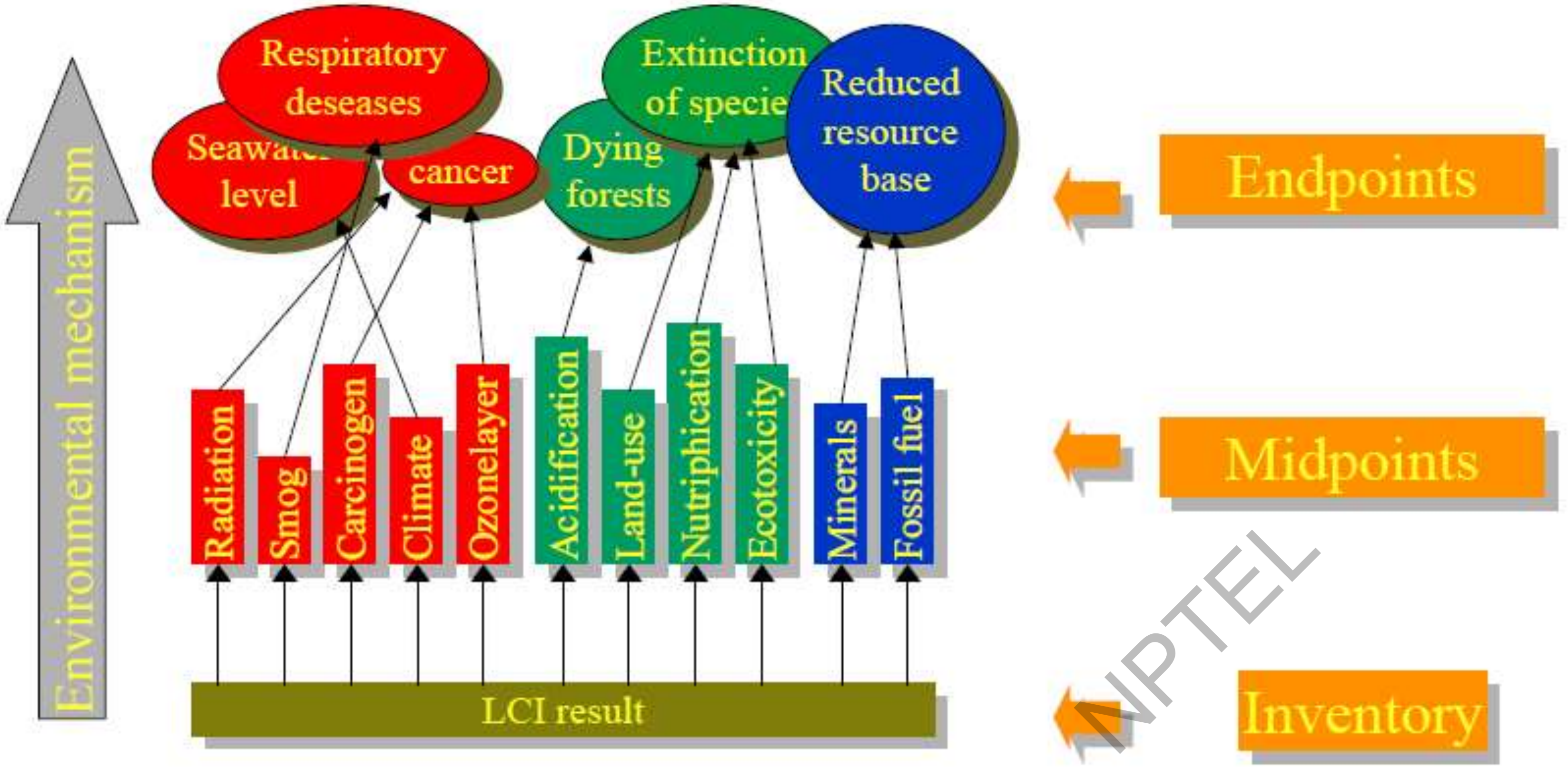


Figure 3: The choice of the impact assessment method depends largely on the audience addressed.



General overview of the structure of an impact assessment method. The LCI results are characterised to produce a number of impact category indicators. According to ISO, one must document the environmental relevance of each indicator by describing the link to the endpoints. Endpoints can be selected by the practitioner, as long as the reasons for including or excluding endpoints are clearly documented.

Life cycle impacts

Elementary flows

Inputs:

Iron ore
Crude oil
Water
Wood
Solar energy
Land use
…

Outputs :

CO_2
SO_2
PM
VOC
PO_4
NO_3
Pesticides
Metals
…

Impact categories

Global warming
Ozone layer depletion
Land use
Natural resource depletion
Acidification
Eutrophication
Photochemical ozone generation
Human toxicity
Ecotoxicity

Single score

IMPACT2002+ = A combined approach

Elementary flows

Impact categories

- Human toxicity
- Respiratory effects
- Ionizing radiations
- Ozone layer depletion
- Photochemical oxydation
- Aquatic ecotoxicity
- Terrestrial ecotoxicity
- Terrestrial acidification/nutrification
- Land occupation
- Aquatic acidification
- Aquatic eutrophication
- Global warming
- Non-renewable primary energy
- Mineral extraction

Damage categories

- **Human health**
- **Ecosystem quality**
- **Climate change**
- **Resources**

From Jolliet et al. (2003) IMPACT2002+

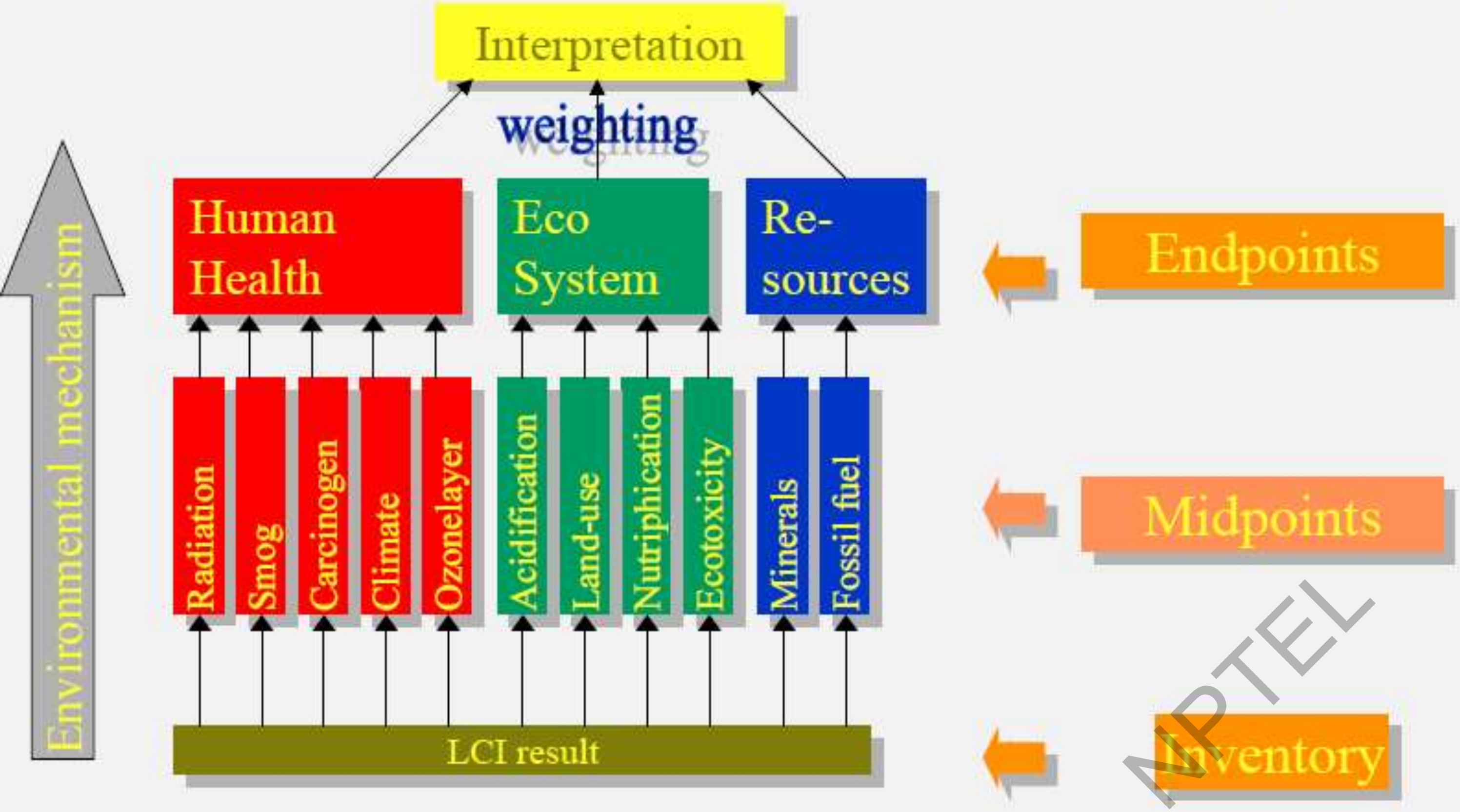


Figure 5: Schematic overview of the methodology proposed by Goedkoop & Spriensma. The environmental models for each impact category are extended up to endpoint level, as the impact category indicators that relate to the same endpoint have a common unit, these indicators can be added. In the case of Ecotoxicity, the endpoint is Ecosystem Quality, expressed as Potential Disappeared Fraction of plants.

The development of LCA

1969

REPA (*Resource and Environmental Profile Analysis*)
Coca-Cola
USA

1984

Environmental report on packaging
Switzerland

1991

1st workshops by SETAC

1st European guidelinesion on eco-labeling

1997

14040 standards

2000

ecoinvent Center

2002

Life Cycle Initiative
UNEP
SETAC

2007

European LCA platform

EPLCA
European Platform on Life Cycle Assessment

2010

Social LCA guidelines

ILCD Handbook

Incorporating LCA in Environmental Decision Making for Waste Management

- Use of LCA tool to assess the best options among the alternatives for waste management program
  - Peel Region, ON, Canada
  - Auckland, New Zealand
  - Evaluation of odour control technologies for compost facilities

Figure 6.2 - Established System 2 – APEFW & Excess Waste to Landfill

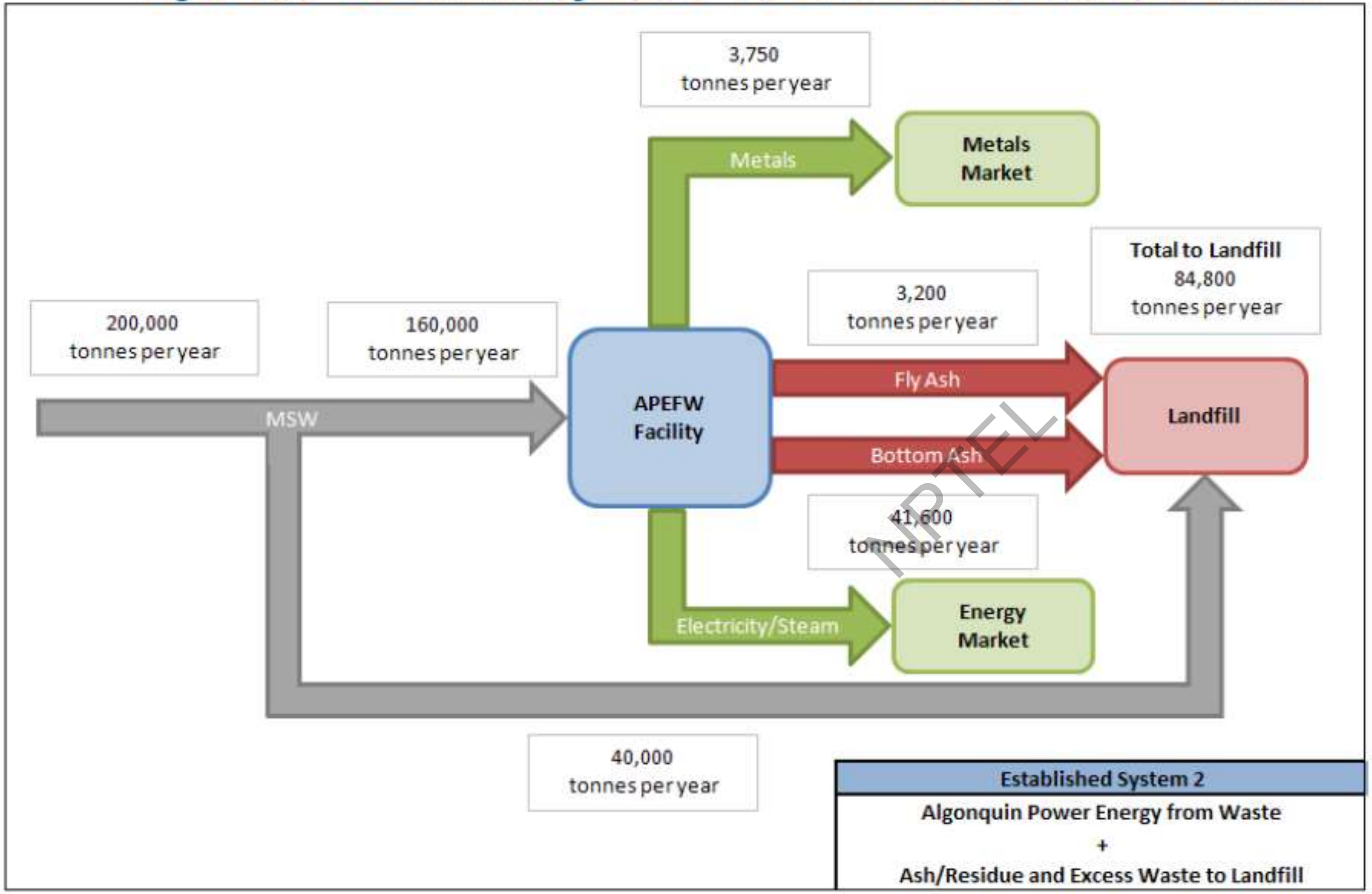


Figure 6.3 - Established System 3 – New Mass Burn Facility with Energy Recovery

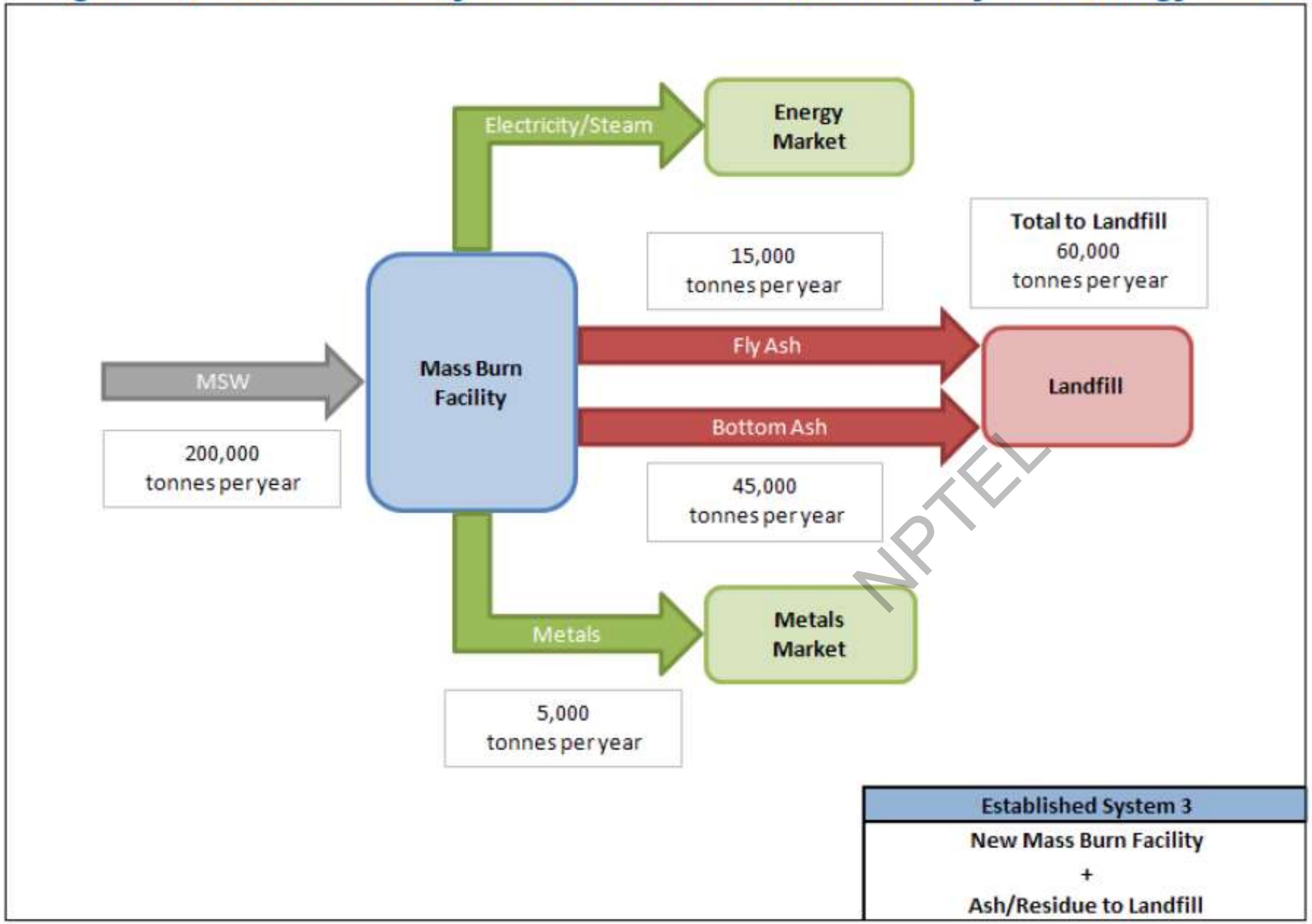
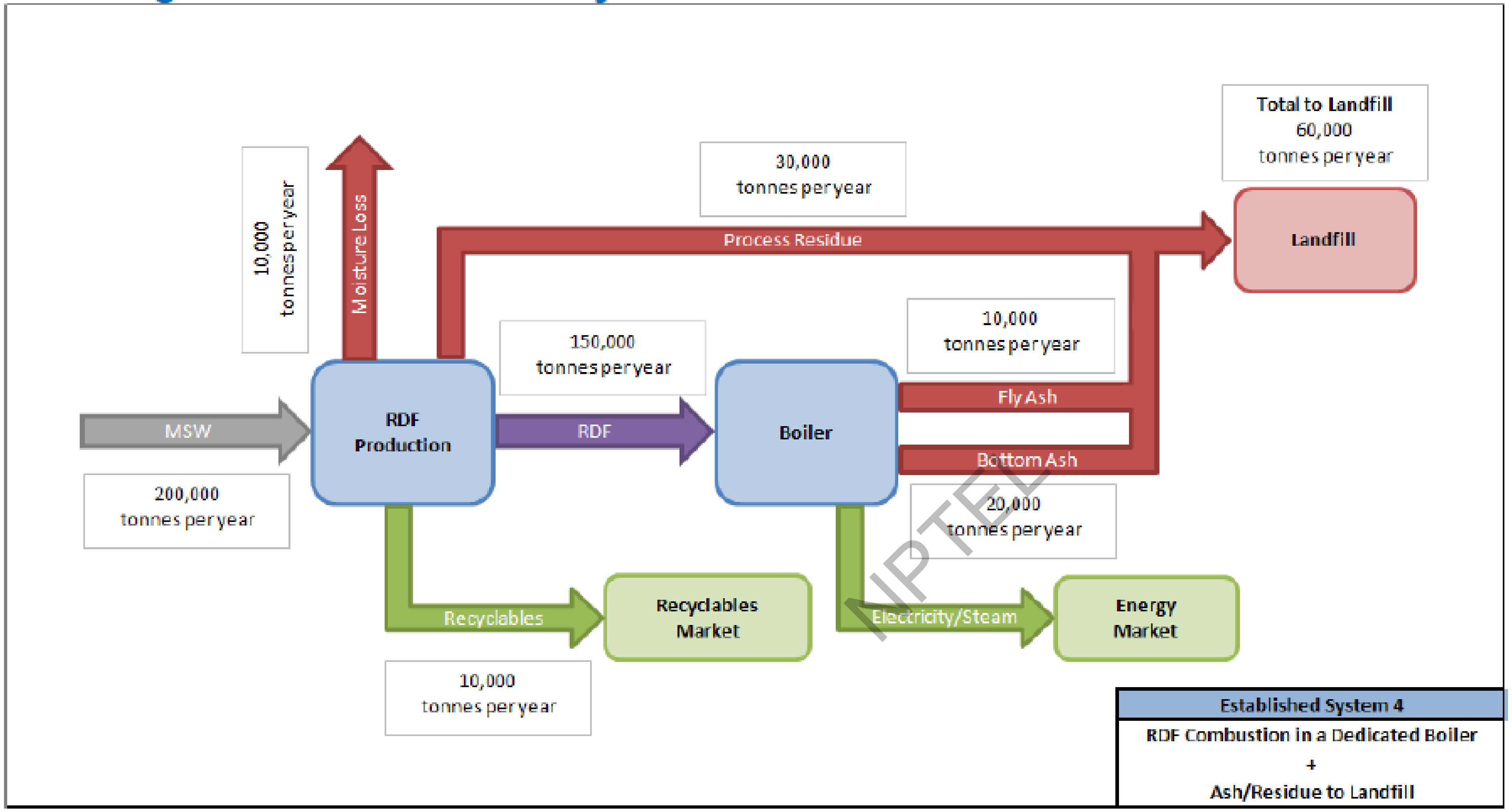
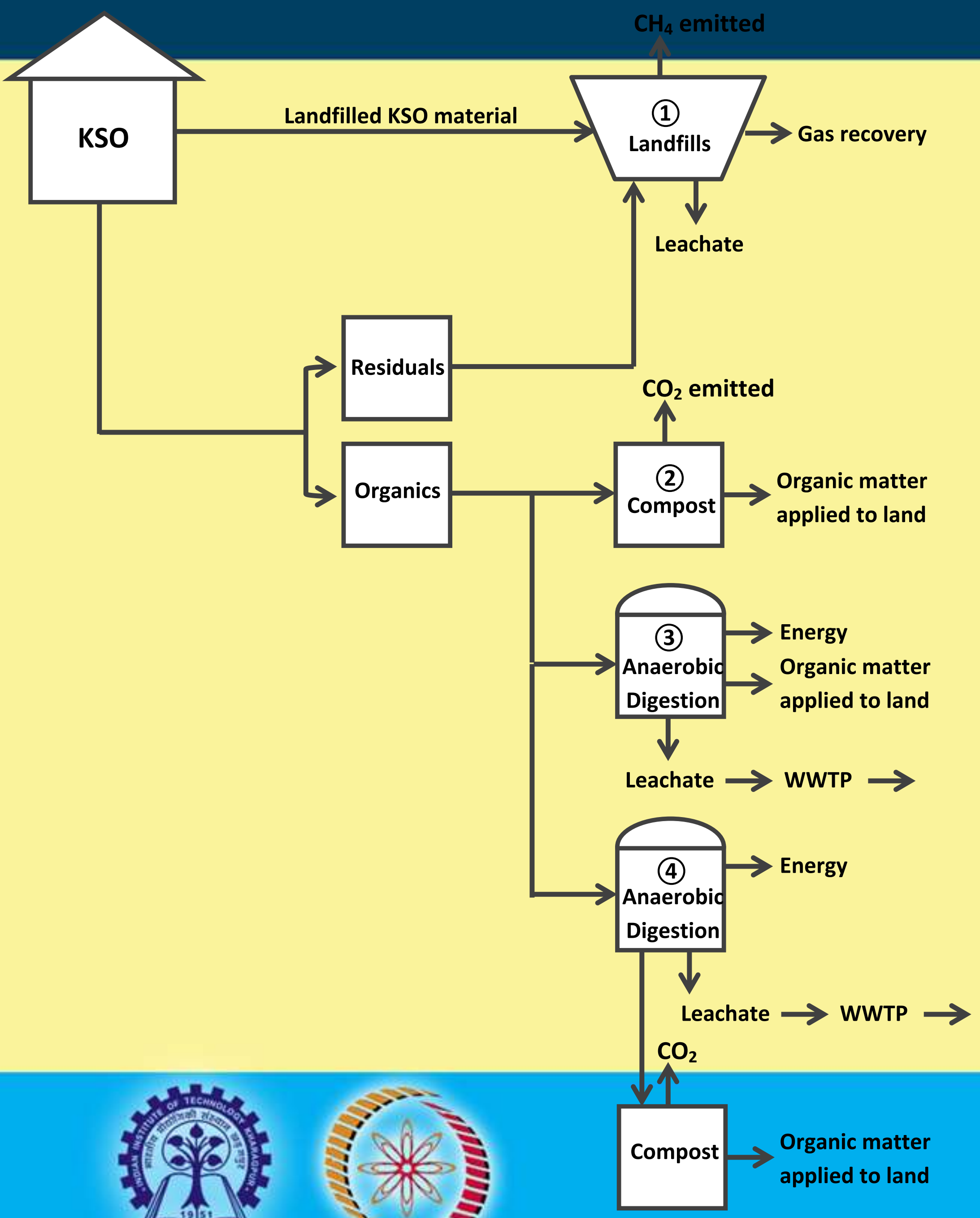


Figure 6.4 - Established System 4 – RDF Combustion in a Dedicated Boiler





Organic Waste diversion from landfill – Case study from Auckland, New Zealand

Food waste anaerobic digestion is environmentally better than composting and other recovery options, and that for garden waste (and for mixtures of food waste) dry anaerobic digestion followed by composting is environmentally better than composting alone.

Conclusion

Conclusion:

In this week, readers learnt about risk assessment, environmental risk assessment and life cycle analysis.

NPTEL ONLINE CERTIFICATION COURSES

Thank you