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A DIAGNOSTIC EXPERT SYSTEM FOR GREEN PRODUCTIVITY ASSESSMENT OF MANUFACTURING PROCESSES

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Green Productivity

- **A term adopted from the Asian Productivity Organization (APO) to refer to environmental and productivity performance**
- **A program of the APO, Green Productivity (GP) is regarded as the key to sustainable development in Asia and the Pacific**
- **GP is the productivity approach to sustainable development**

Green Productivity

Productivity Improvement ⇒ **Framework for Continuous Improvement**

Environmental Performance ⇒ **Foundation for Sustainable Development**

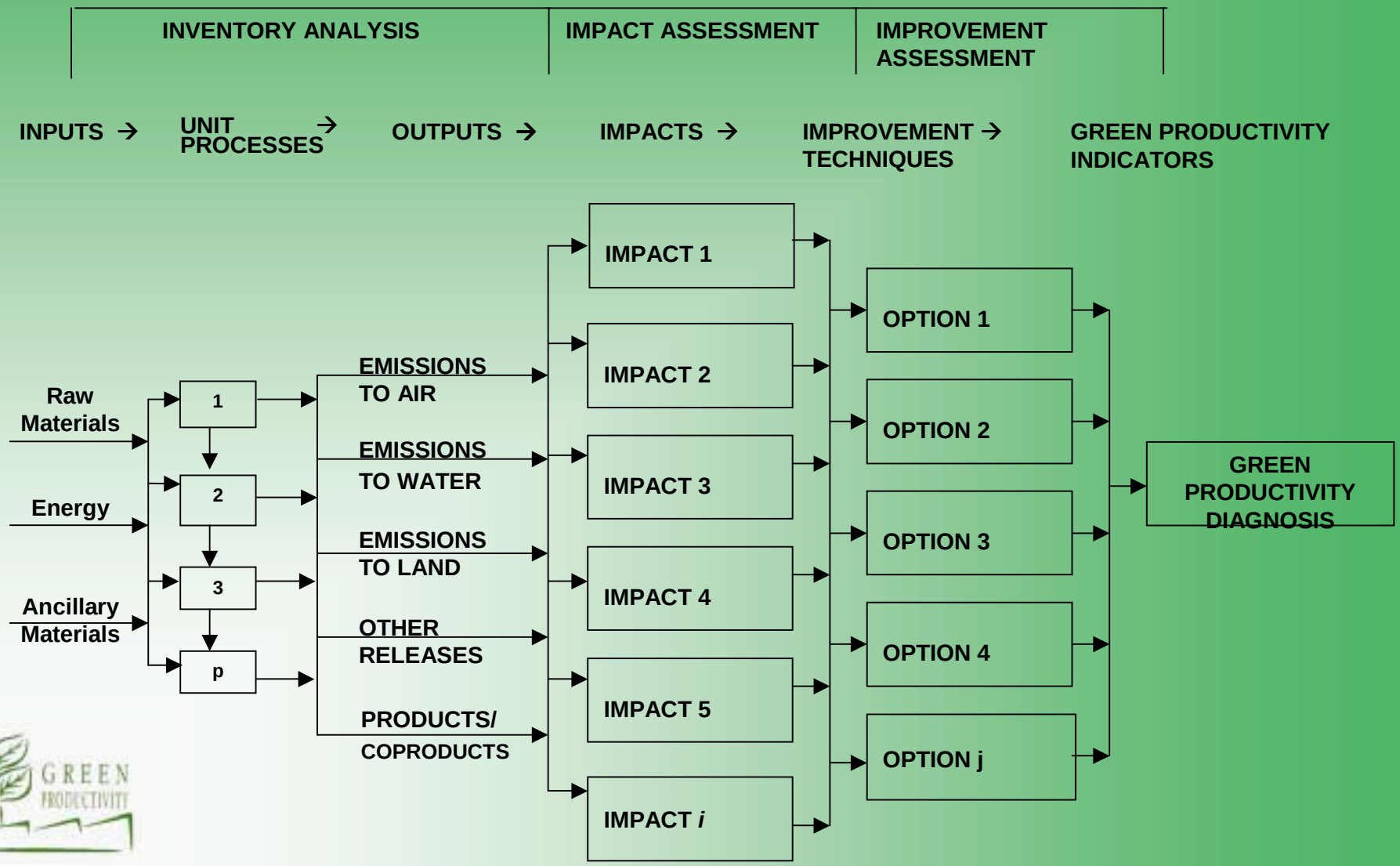
The Green Productivity Integrated Methodology

- **Life cycle assessment (LCA)**
- **Analytic hierarchy process (AHP)**
- **Expert system (ES)**

LCA

- **The technical framework by which (impact) factors and (improvement) options in decision making are identified.**
- **Rationalizes the structure of the knowledge base that spans inventory analysis, impact assessment and improvement assessment**
- **A streamlined LCA is undertaken limiting the number of parameters for inventory and impact assessment within a gate-to-gate analysis**

Conceptual Framework for GP Assessment

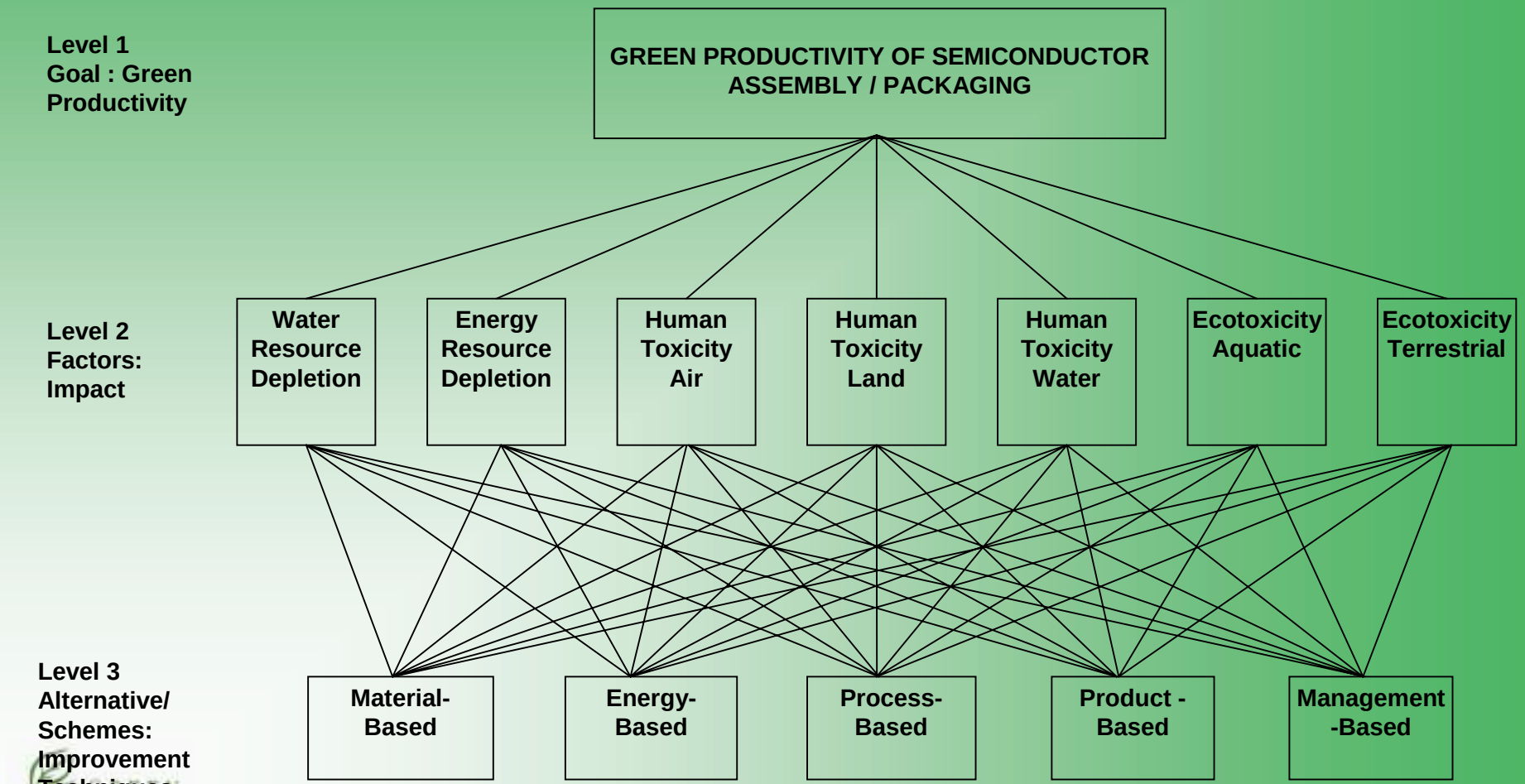


AHP

- **Provides the decision framework and the weighting or valuation tool in impact and improvement assessment for the design of a set of weighting factors which can serve as basis for decision making**

- **Features hierarchical structuring of decision elements into impacts and improvement options, pairwise comparison of elements using a rating scale of 1 to 9, mechanism for consistency check , may utilize a panel of experts or decision makers and uses geometric means to determine aggregate results**

Decision Hierarchy Structure



Determination of AHP Priority Weights

$$A_j = \Sigma W_i K_{ij}$$

i = 1, 2, …n impact factors

j = 1, 2, …m options

where W_i = the relative weight of impact factor *i* with respect to the over-all goal

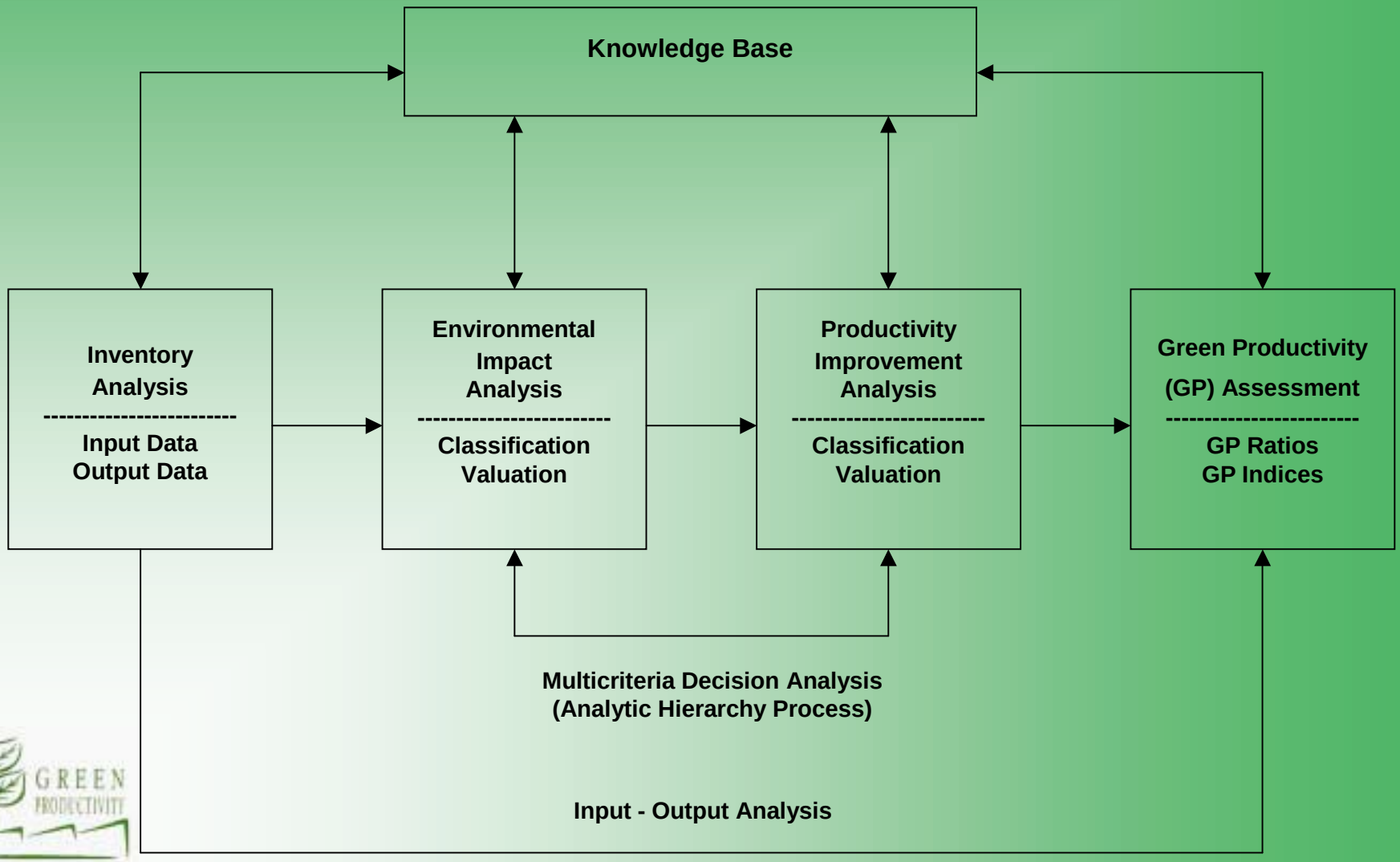
K_{ij} = relative weight of option *j* with respect to impact *i*

A_j = priority weight of option *j.*

The Diagnostic Expert System

- Expert system technology is explored to develop a software prototype that emulates how human experts diagnose GP performance of manufacturing processes.

GP Expert System Model Structure



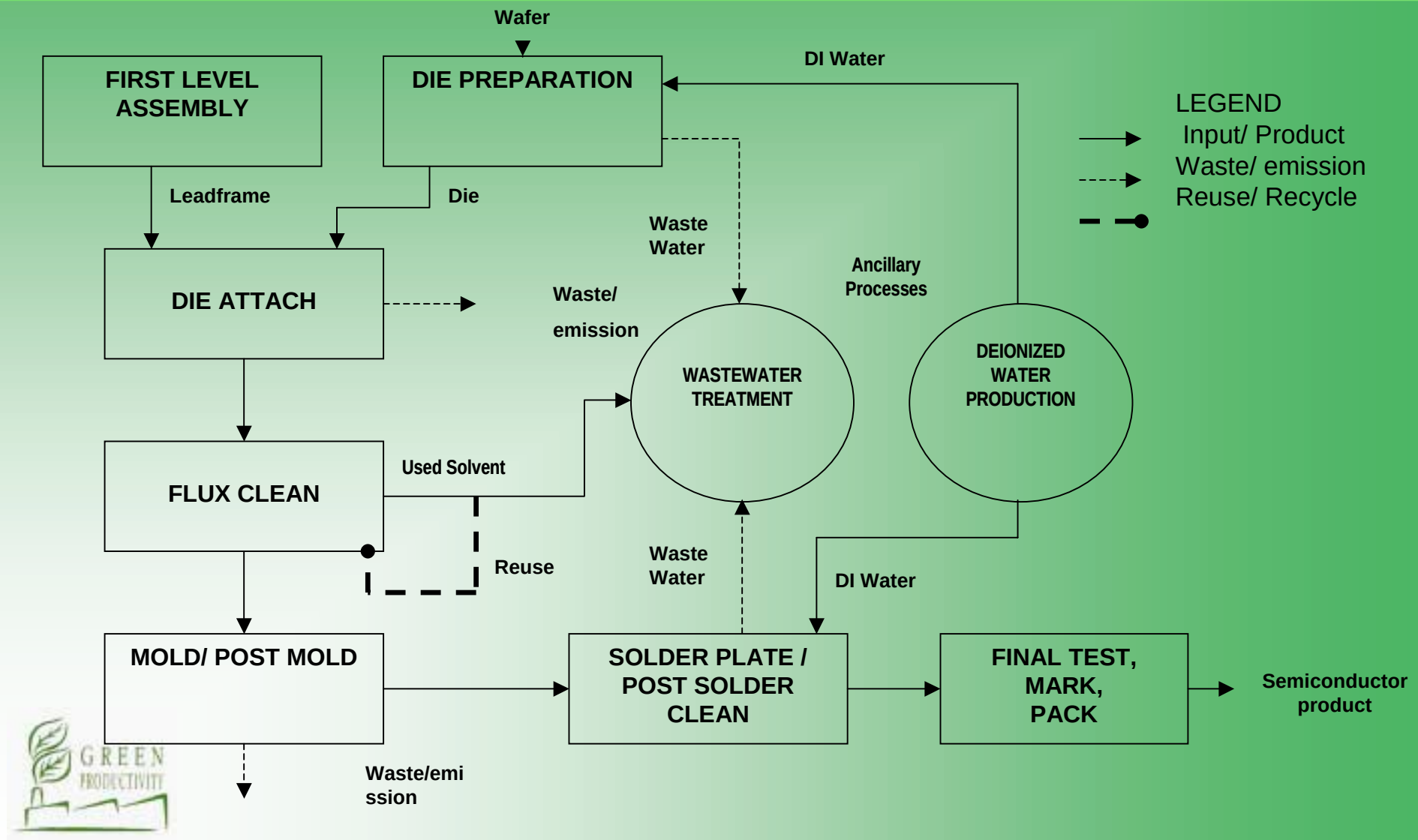
GP Model Subsystems

- **Measurement Subsystem** - employs a database program for importing data and calculations in inventory, impact, improvement, and GP assessment; FoxPro for Windows is used for the database program.
- **Diagnostic Subsystem** - interpretation of inventory data, impact weights, improvement priority weights, and GP ratios/indices; CLIPS (C Language Integrated Production System) is used for the expert system program.

The Diagnostic Module

- Performs impact classification based on the inventory data
- Reads environmental impact and improvement priority weights from AHP calculations as well as green productivity performance ratios and indices
- Knowledge processing is performed on the passed parameters from the database to the expert system
- The output consists of diagnostic advice on the result of inventory analysis, impact assessment, improvement assessment and green productivity assessment.

Application: Semiconductor Assembly/ Packaging Process



Model Parameters for Impact Assessment

Impact	Acronym	Indicator	Process
Water Resource Depletion	WRD	DI water	Die Preparation Solder Plating
		Tap water	Die Preparation Die Attach Molding Solder Plating
Energy Resource Depletion	ERD	Electricity	All Processes
Human Toxicity-Air	HTA	Pb Vapor	First Level Assembly Die Attach
Human Toxicity- Land	HTL	Heavy metal wastes (CU-Sn-Ni)	First Level Assembly Solder Plating
Human Toxicity-Water	HTW	Waste water (acidic)	Solder Plating
Ecotoxicity- Aquatic	ETA	Methylene Chloride (Waste organic solvent)	Flux Cleaning
Ecotoxicity –Terrestrial	ETT	Mold runners	Molding

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Model Parameters for Improvement Assessment

Improvement Technique	ACRONYM	Description
Material-based techniques	MBT	Raw material substitution or usage reduction of (non-renewable, hazardous, toxic) primary raw materials/ chemicals with renewable, non-hazardous or non-toxic materials
Energy -based techniques	EBT	Energy substitution or usage reduction by use of high efficiency equipment, improve transfer efficiency by minimizing energy losses due to poor insulation, use environment-friendly energy sources
Process- or equipment-based techniques	PET	Process or equipment modification for higher efficiency, reconditioning to produce less waste, in-plant recycling process, in-plant segregation techniques for reusable waste e.g. solvent extraction process integration of air, water and other pollution controls; automation.
Product-based techniques	PBT	Improving product quality in relation to defects and end-of-life disposal aspects; product quality control and standardization; product design innovation for environmental compatibility.
Management-based techniques	MGT	Management strategies not included in the first 4 classification e.g., good housekeeping practices, employee training, proper inventory management to reduce waste in the production process or other functions.

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Relative Weights of Options (Aj) to Improve Green Productivity Performance of Semiconductor Assembly/Packaging

AGGREGATE RESULTS

Impacts	WRD	ERD	HTA	HTL	HTW	ETA	ETT	
Rel. wt of impacts, Wi	0.14	0.13	0.13	0.15	0.12	0.12	0.21	
Options	Relative weight of options with reference to impacts, Kij							Aj
MBT	0.19	0.15	0.24	0.42	0.26	0.31	0.34	0.28
EBT	0.17	0.32	0.16	0.15	0.15	0.16	0.14	0.18
PET	0.38	0.30	0.27	0.24	0.25	0.22	0.24	0.27
PBT	0.12	0.10	0.13	0.12	0.13	0.14	0.11	0.12
MGMT	0.14	0.13	0.19	0.14	0.21	0.17	0.18	0.17

Impacts	Improvement Options
Water Resource Depletion (WRD)	Material-based Technique (MBT)
Energy Resource Depletion (ERD)	Energy-based Technique (EBT)
Human Toxicity in Air (HTA)	Process/Equipment-based Technique (PET)
Human Toxicity on Land (HTL)	Product-based Technique (PBT)
Human Toxicity in Water (HTW)	Management-based Technique (MGMT)
Ecotoxicity-Aquatic (ETA)	
Ecotoxicity-Terrestrial (ETT)	

Wi = priority weight of impact factor i with reference to Green Productivity Performance
Kij = relative weight of option j with reference to impact factor i
Aj=priority weight of option j.

Green Productivity Indicators

Green Productivity (GP) Indicators	ACRONYM	GP Ratio Determination	GP Index
GP Water Utilization Ratio	GPWUR	kg product / kg water input	GPWUI
GP Energy Utilization Ratio	GPEUR	kg product / kw-hr energy input	GPEUI
GP Human Toxicity-Air Emission Ratio	GPHAR	kg product / kg HTA emission	GPHAI
GP Human Toxicity-Water Waste Ratio	GPHWR	kg product / kg HTW waste	GPHWI
GP Human Toxicity-Land Waste Ratio	GPHLR	kg product / HTL waste	GPHLI
GP Ecotoxicity-Aquatic Waste Ratio	GPEAR	Kg product / ETA waste	GPEAI
GP Ecotoxicity-Terrestrial Waste Ratio	GPETR	kg product / ETT waste	GPETI

Input - Output Analysis

$$Mass_{in} = Mass_{out} \quad (1)$$

$$Energy_{in} = Energy_{out} \quad (2)$$

The total amount of a specific material *m* for *i* unit processes is:

$$M = \sum_{i=1}^{n} m \quad (3)$$

The total amount of specific energy *e* for *i* unit processes is:

$$E = \sum_{i=1}^{n} e \quad (4)$$

The total amount of a specific waste or emission from a unit process (i) to medium (j), where j = 1 to 3 corresponding to air, water or land and for n unit processes is:

$$W_{ij} = \sum_{i=1}^{n} \sum_{j=1}^{3} wij \quad (5)$$

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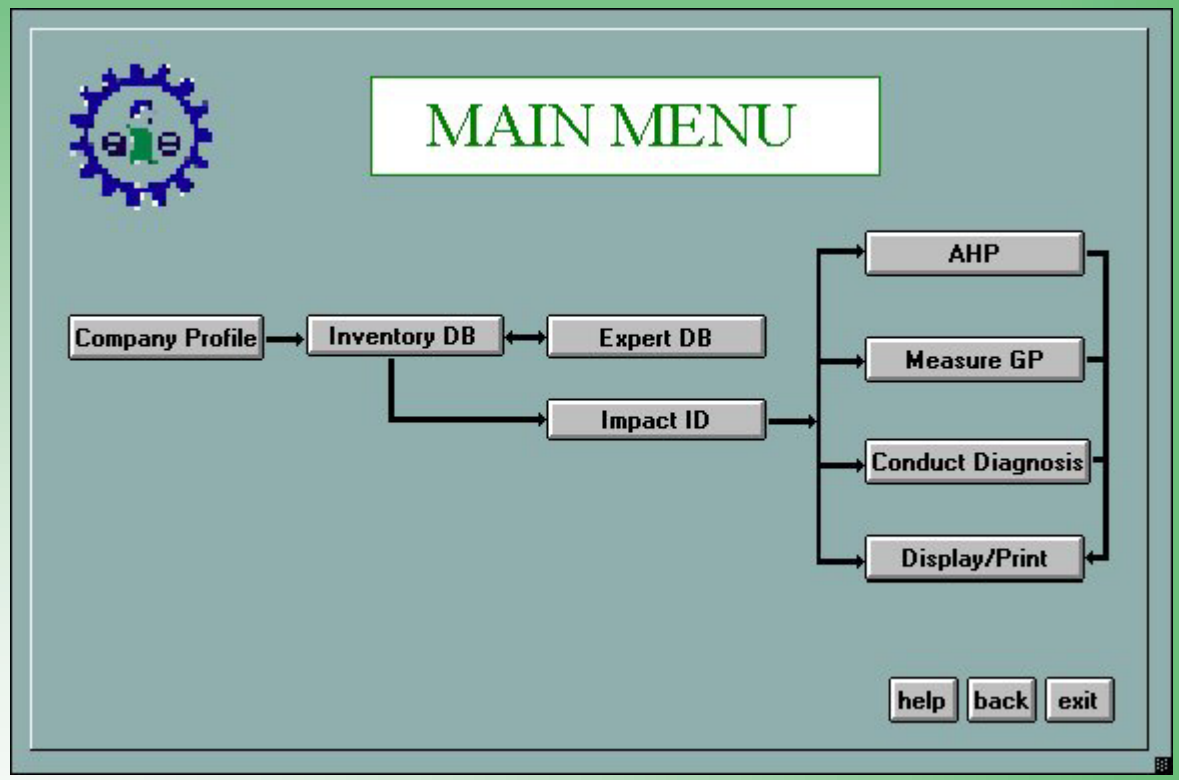
Green Productivity Ratios and Indices

GREEN PRODUCTIVITY INDICATORS	Base Scenario GP Ratio	Base Scenario GP Index	Test Scenario GP Ratio	Test Scenario GP Index	Benchmark Analysis	Diagnostic Interpretation
GP Water Utilization	0.002053	1.000000	0.002131	1.038224	>1	Improved GP based on product to water ratio
GP Energy Utilization	0.043383	1.000000	0.050640	1.167285	>1	Improved GP based on product to energy ratio
GP Human Toxicity - Land	3.693001	1.000000	3.694029	1.000278	>1	Improved GP based on product to HTL waste ratio
GP Terrestrial Ecotoxicity	4.345793	1.000000	4.345793	1.001356	>1	Improved GP based on product to ETT waste ratio
GP Human Toxicity -Water	0.010129	1.000000	3.678199	1.000668	>1	Improved GP based on product to HTW waste ratio
GP Aquatic Ecotoxicity	5.985417	1.000000	5.989602	1.000699	>1	Improved GP based on product to ETT waste ratio
GP Human Toxicity - Air	39.238605	1.000000	39.266035	1.000699	>1	Improved GP based on product to HTA emission ratio

Test Scenario : With PLC Modification

Menu Screen for GP Assessment



Conclusion/Future Work

- Green productivity provides an open framework that can incorporate several strategies for sustainable manufacturing.
- The GP assessment methodology and computerized diagnostic prototype may be utilized as an internal management or self-assessment tool by companies in their continuous improvement strategies.
- The application of expert system technology is particularly appropriate to provide flexibility in testing assumptions and in preserving human expertise on green productivity program implementation.
- Enhancements may be made in future versions with a more comprehensive scope to include other pertinent life cycle stages, consider impact characterization differentiated into global, regional and local conditions and applicability on different industries when reliable databases become available.
- The GP diagnostic software may be integrated with some optimization software for improving industry performance.

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