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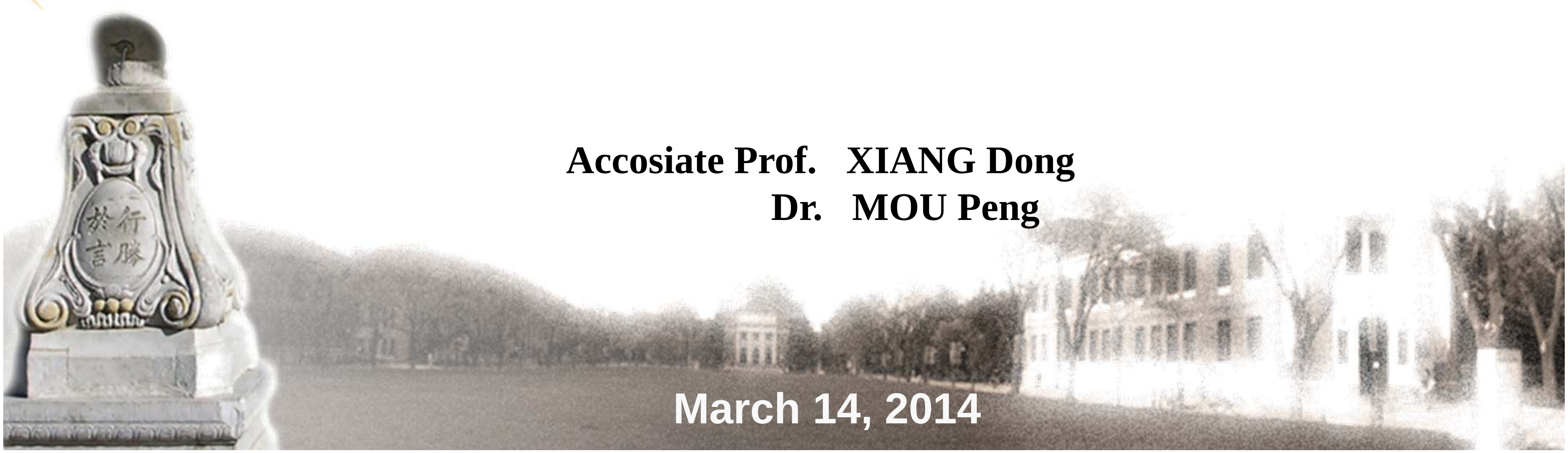
机械工程系 绿色制造实验室

Department of Mechanical Engineering

US-China SM Workshop, HUAZHONG University of Science and Technology, Wuhan, March 13-15, 2014

Method and Application of Sustainable Design for Energy and Material Saving Based on Energy Flow Analysis



Accosiate Prof. XIANG Dong

Dr. MOU Peng

March 14, 2014

Members of GM Laboratory

Prof.
DUAN Guanghong

Associate Prof.
XIANG Dong

Associate Prof.
LIU Xueping

Assistant Researcher
MOU Peng

- **4 Staff**
- **6 PHD candidates, 5 Master graduate students**
- **Cultivated 21 masters and 10 doctors.**

GM Laboratory

TOPSEARCH

The first green manufacturing research center between university and enterprise in China(2001).

2001: Establishment Ceremony of Tsinghua Topsearch R&D Center

Introduction

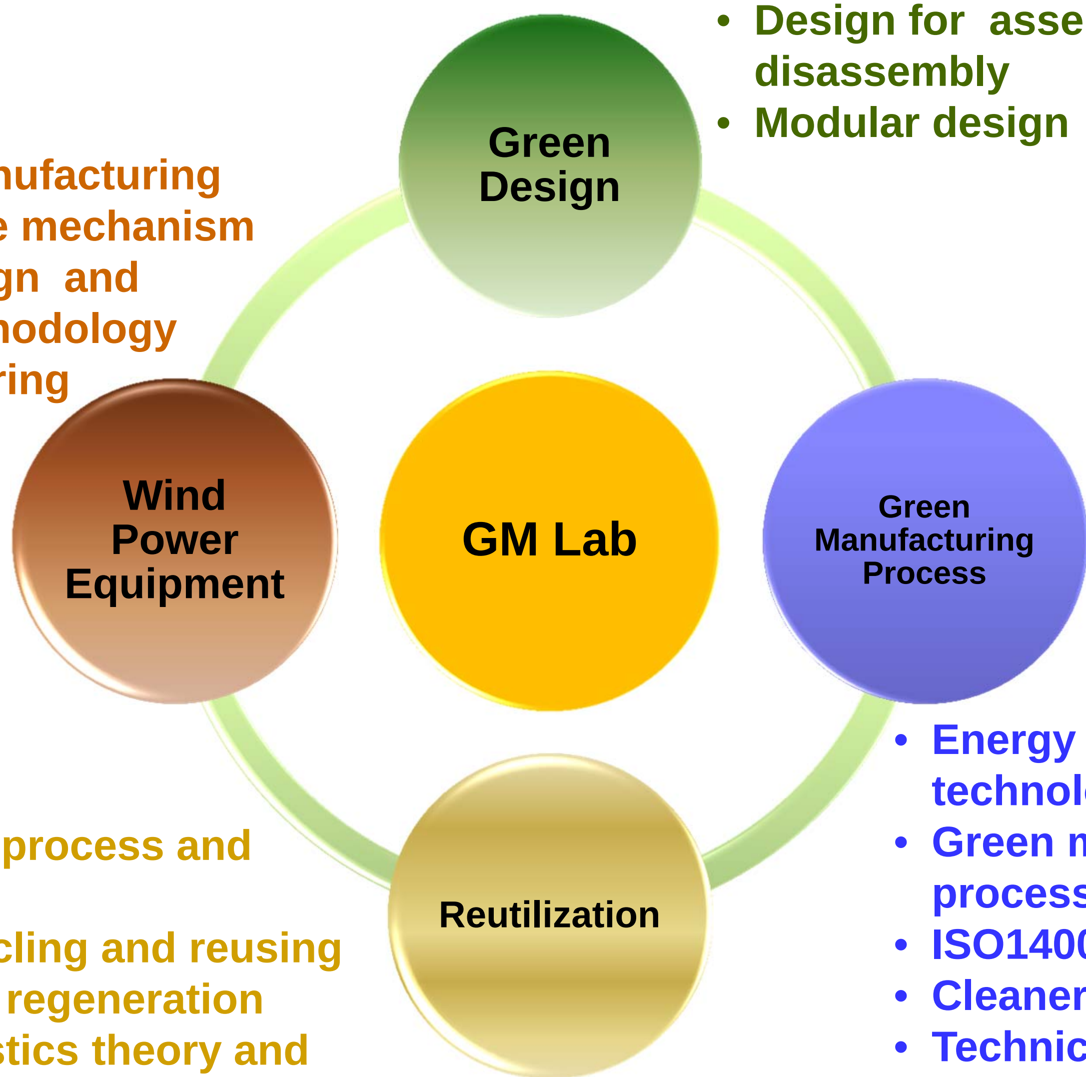
GM Laboratory

2011: Tsinghua - Changhong Joint Laboratory of Advanced Audiovisual Technology

Research areas

- LCA Analysis and low carbon design
- Design based on energy flow
- Design for assembly and disassembly
- Modular design

- Design and manufacturing
- Fatigue damage mechanism
- Reliability Design and Evaluation Methodology
- Service monitoring



- Energy saving production technology
- Green manufacturing process modeling
- ISO14000
- Cleaner production
- Technical standards

- Disassembly process and equipment
- E-waste recycling and reusing
- Scrap rubber regeneration
- Reverse logistics theory and technology

Introduction

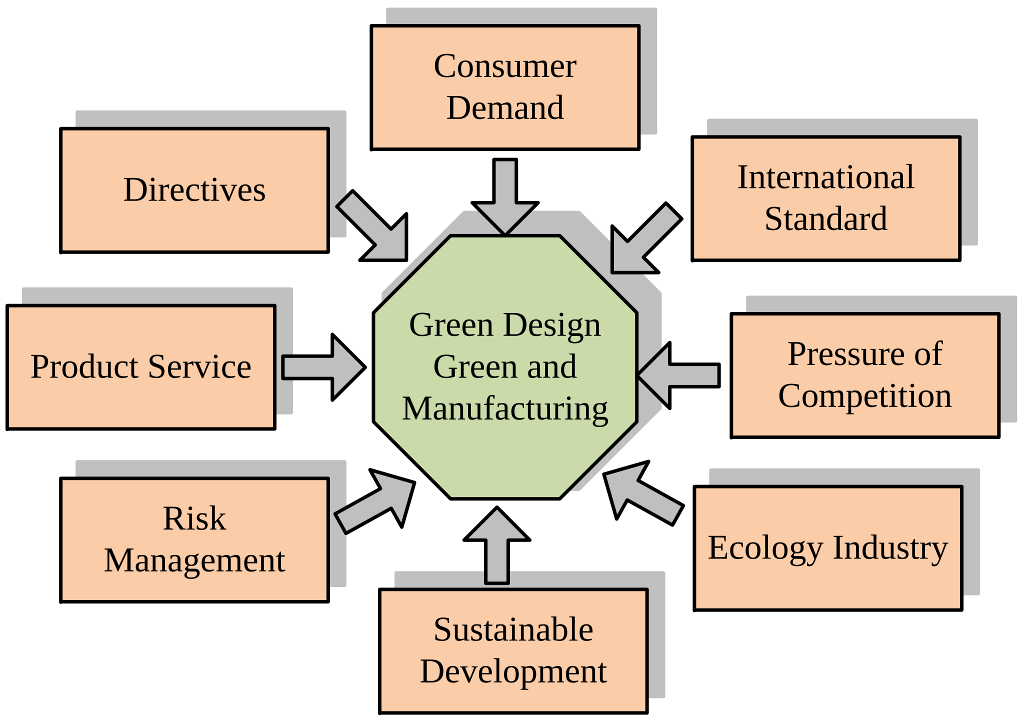
Green Design modeling based on production system

■ Project

- **NSFC Key Project**: **Green design theory and method for electromechanical products**

NSFC
(2000-2003)

■ Driving Forces of Green Design



Green Design Integrated Software Platform

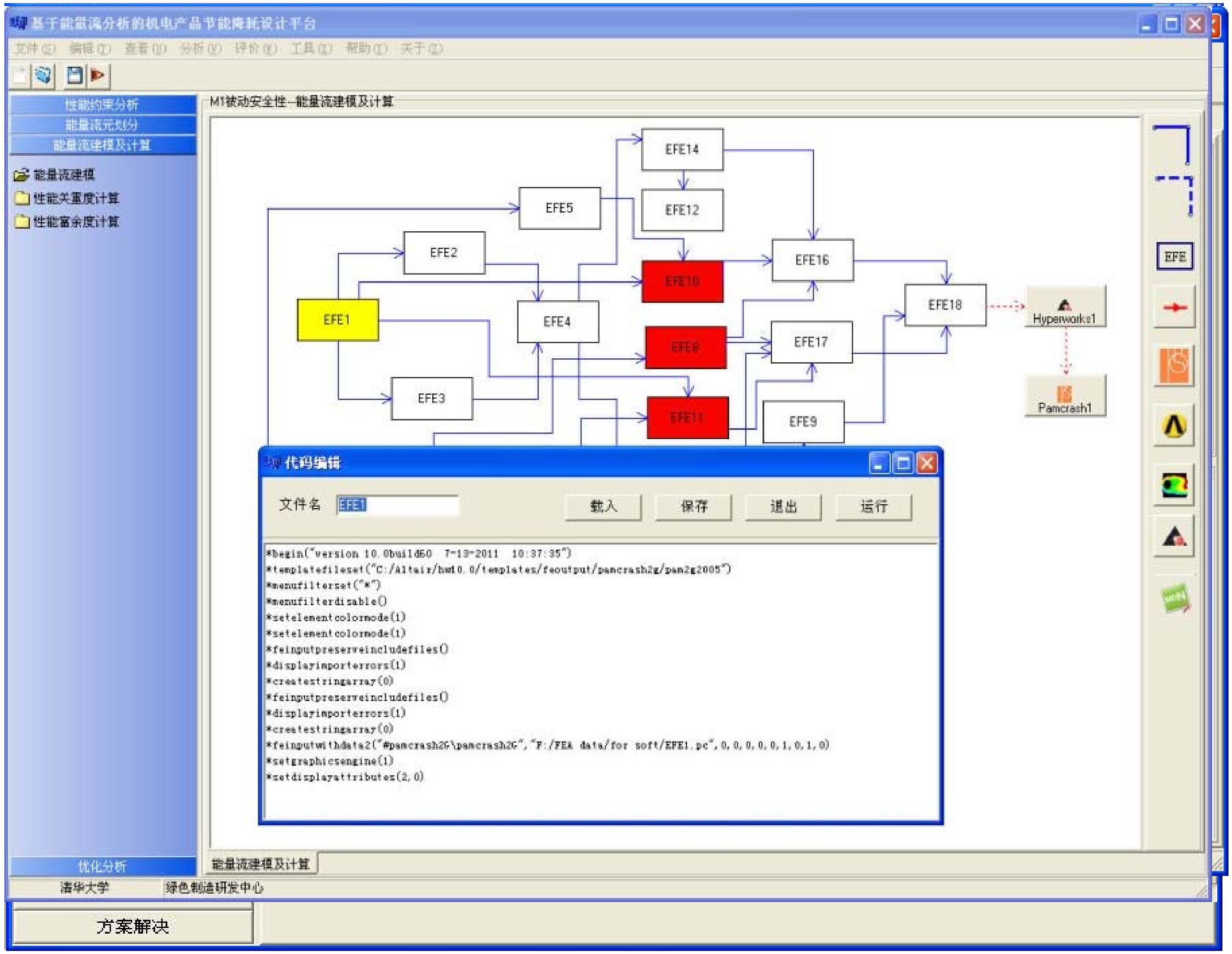
Main interface

Conceptual design

LCA analysis

Modular design

Design based on energy flow



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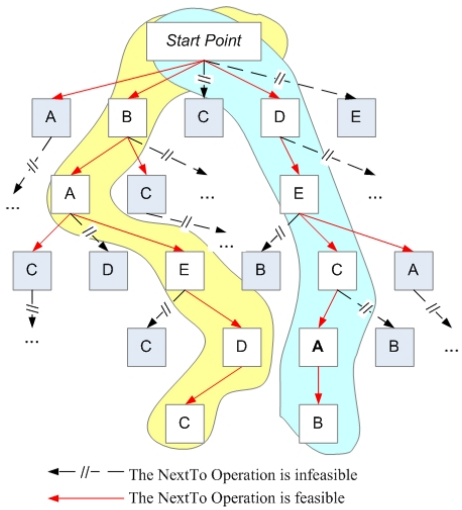
Tsinghua University, Beijing, China

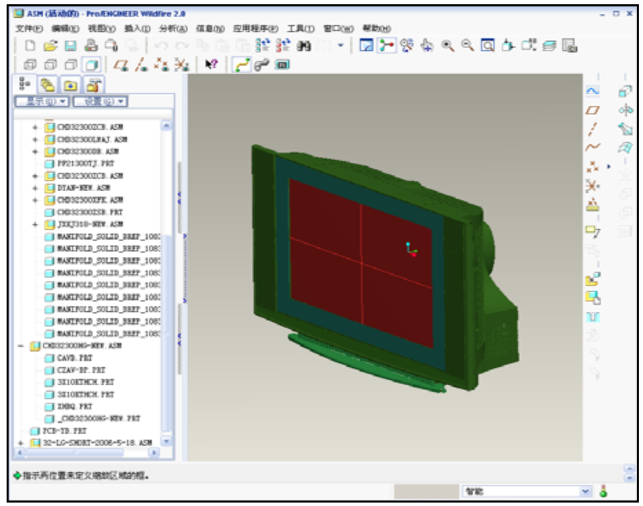
Introduction

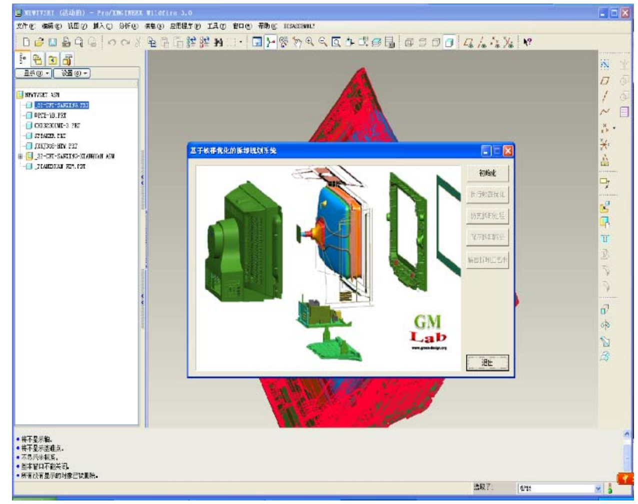
Design for disassembling

■ Disassembly planning and management

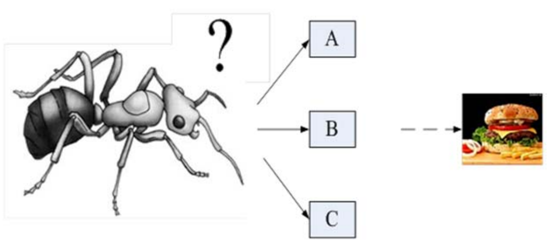


Disassemble Feasibility Information Graph (DFIG)





Disassembly Planning on CAD Platform



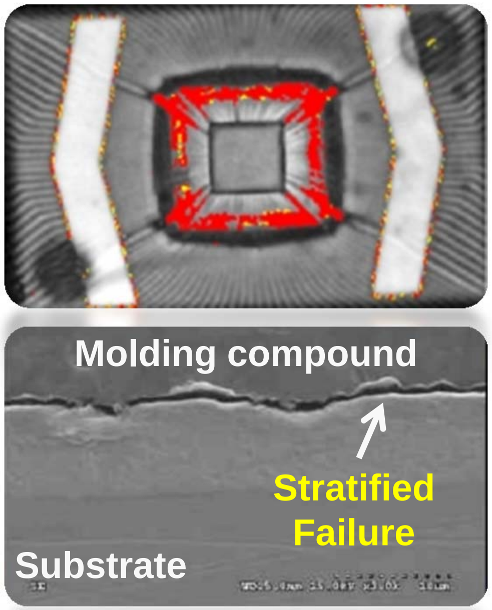
Ant Colony Optimization (ACO)

Application in CRT disassembling line

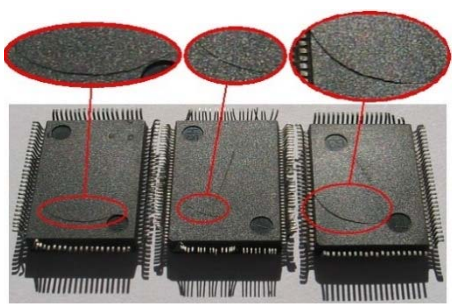
Introduction

Reuse of Disassembled IC Chips

Stratified failure and optimization of disassembling

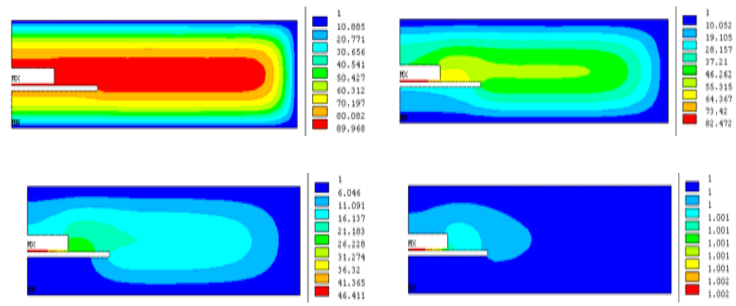


Ultrasound scan and SEM of disassembled IC chips

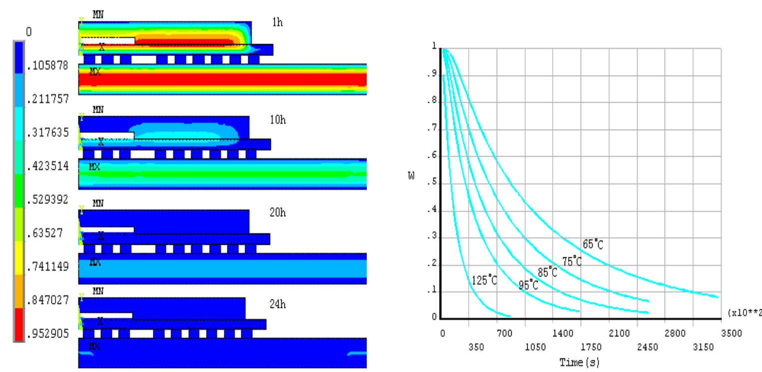


Popcorn effect

□ Stratifying Mechanism



□ Diffusing of Humidity



FEA Analysis of Drying Process

NSFC

(2011-2013)

Introduction

PCB disassembling

Industrialized of PCB Disassembling Equipment

- **Reusable components exceed 92%**
- **Disassembling rate exceed 98% (Tested by China Household Electrical Appliances Association- CHEAA)**

PCB disassembling equipment and disassembled components

PCB recycling process

Crushing

Separation

PCB

- Closed system
- No waste discharge
- Separation rate exceed 95%

Metal

Nonmetal

■ PCB recycling factory

Shaoguan, Guangdong Province

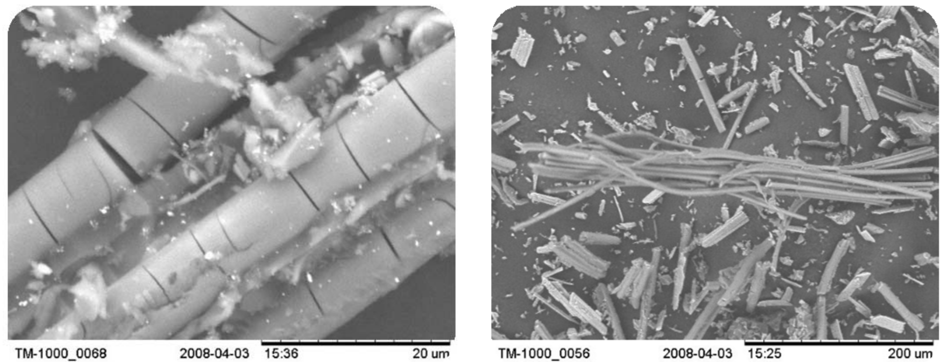
(Demonstration Base of National 863 Program)

Introduction

Reuse of PCB nonmetals

Research and application

PCB nonmetals



Morphology of PCB nonmetals

Traffic Signs (BEI Jing)

Surf boat

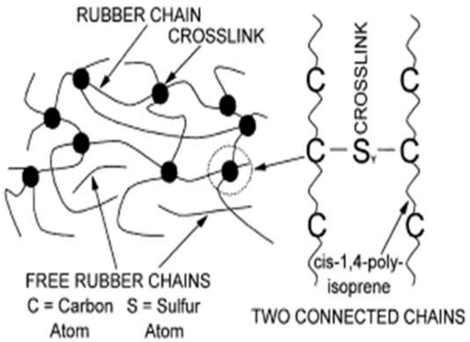
Grates

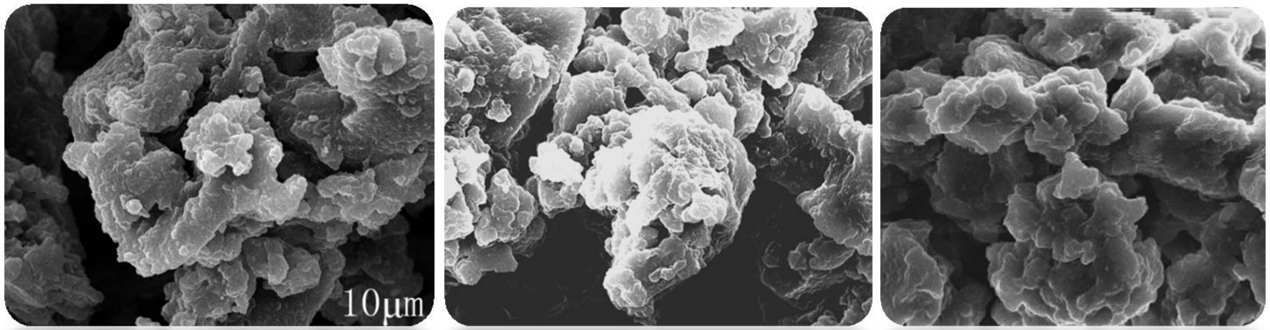
Introduction

Mechanochemistry Regeneration Technology of Waste Rubber

Black pollution

- The annual amount of waste tyres reach to 0.2 billion;
- The weight of waste tyres has exceeds 3 million tons;
- Waste rubber products accounts for 1% of the total industrial solid waste;





Rubber particles after fine grinding, surface activation and re-grinding

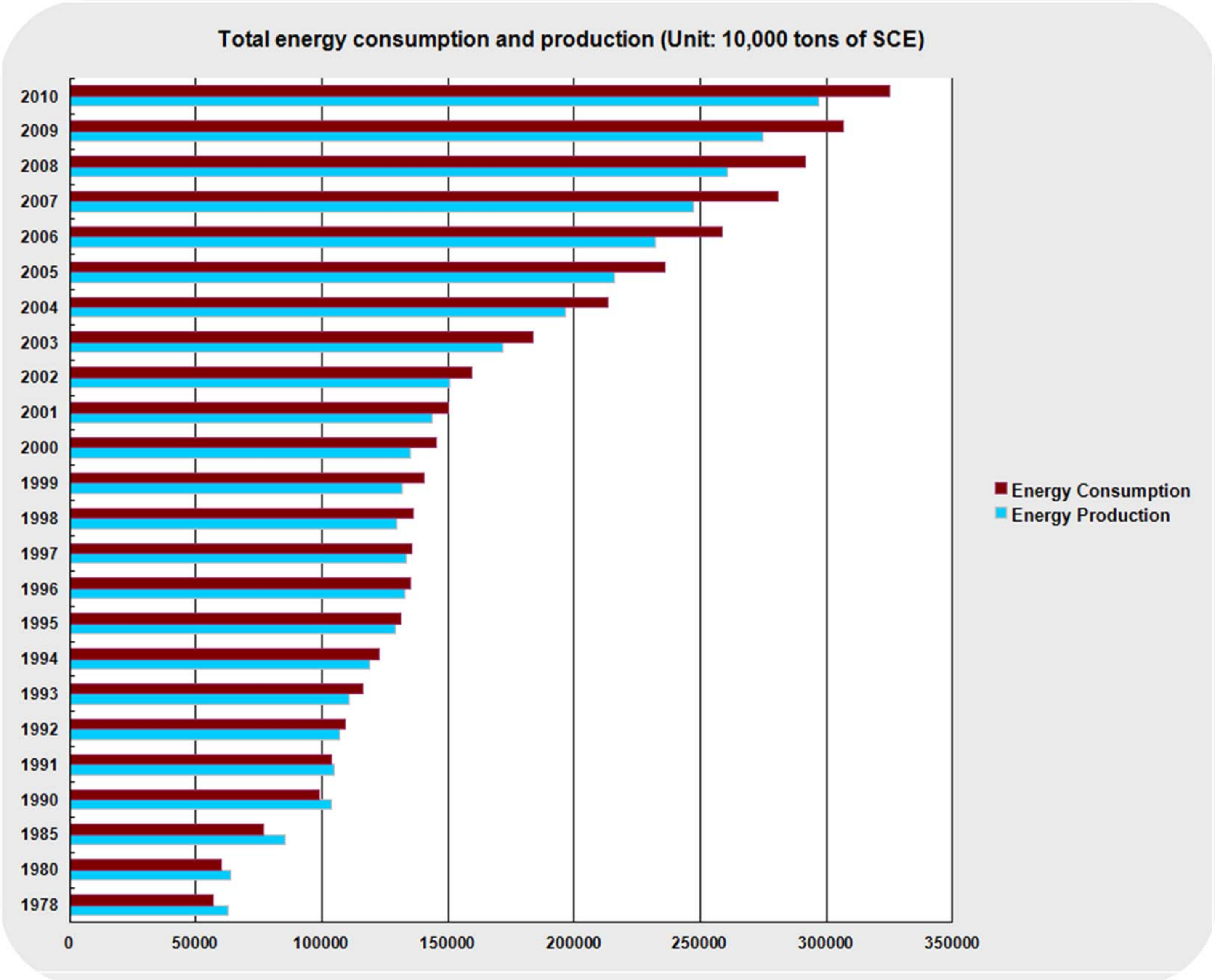
年处理2万吨废轮胎生产精细胶粉成套设备生产线—轮胎输送

年处理2万吨废轮胎生产精细胶粉成套设备生产线

NSFC (2009-2011)

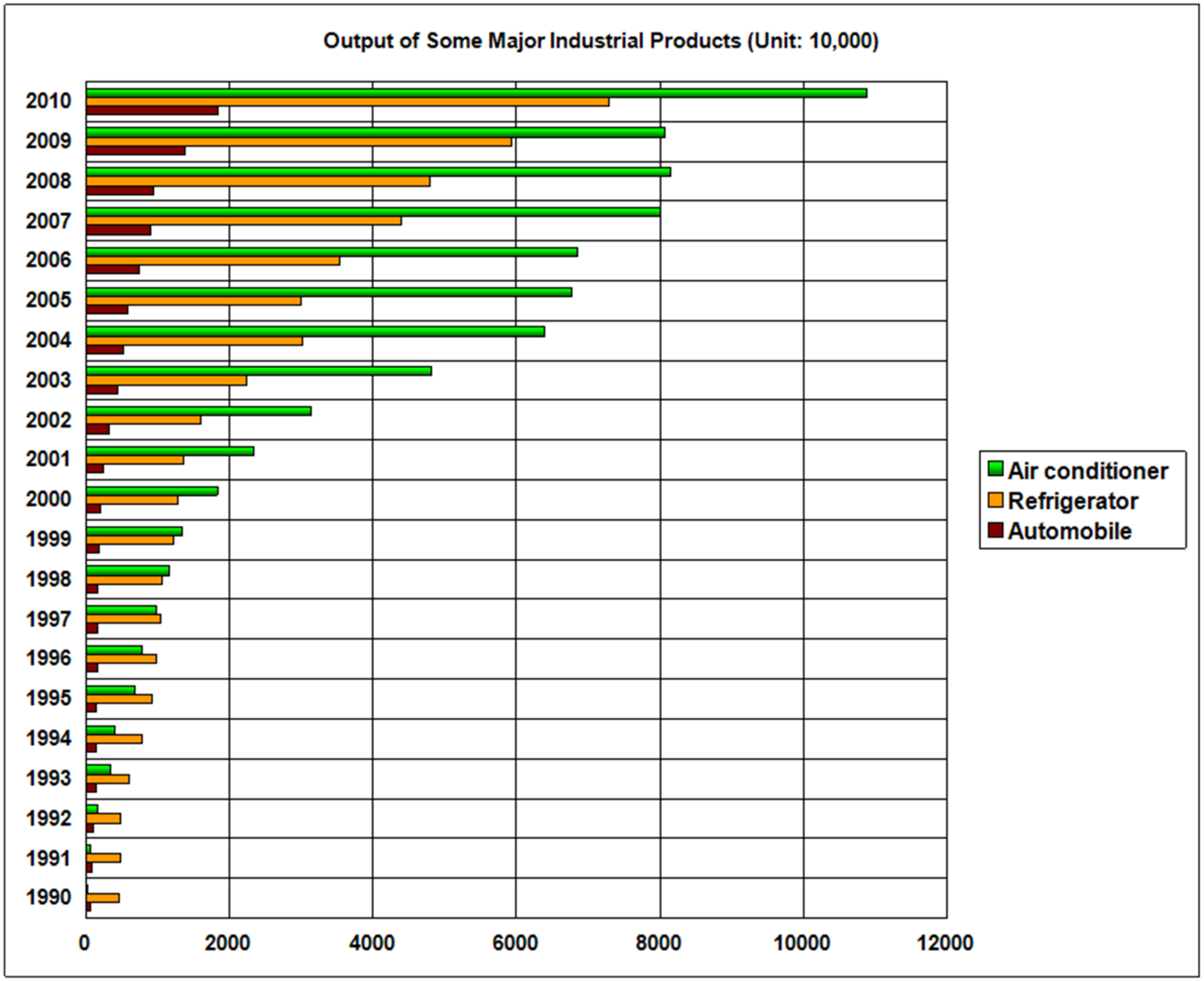
Background

Energy Consumption and Production of China



Background | **Energy Security and Energy Crisis**

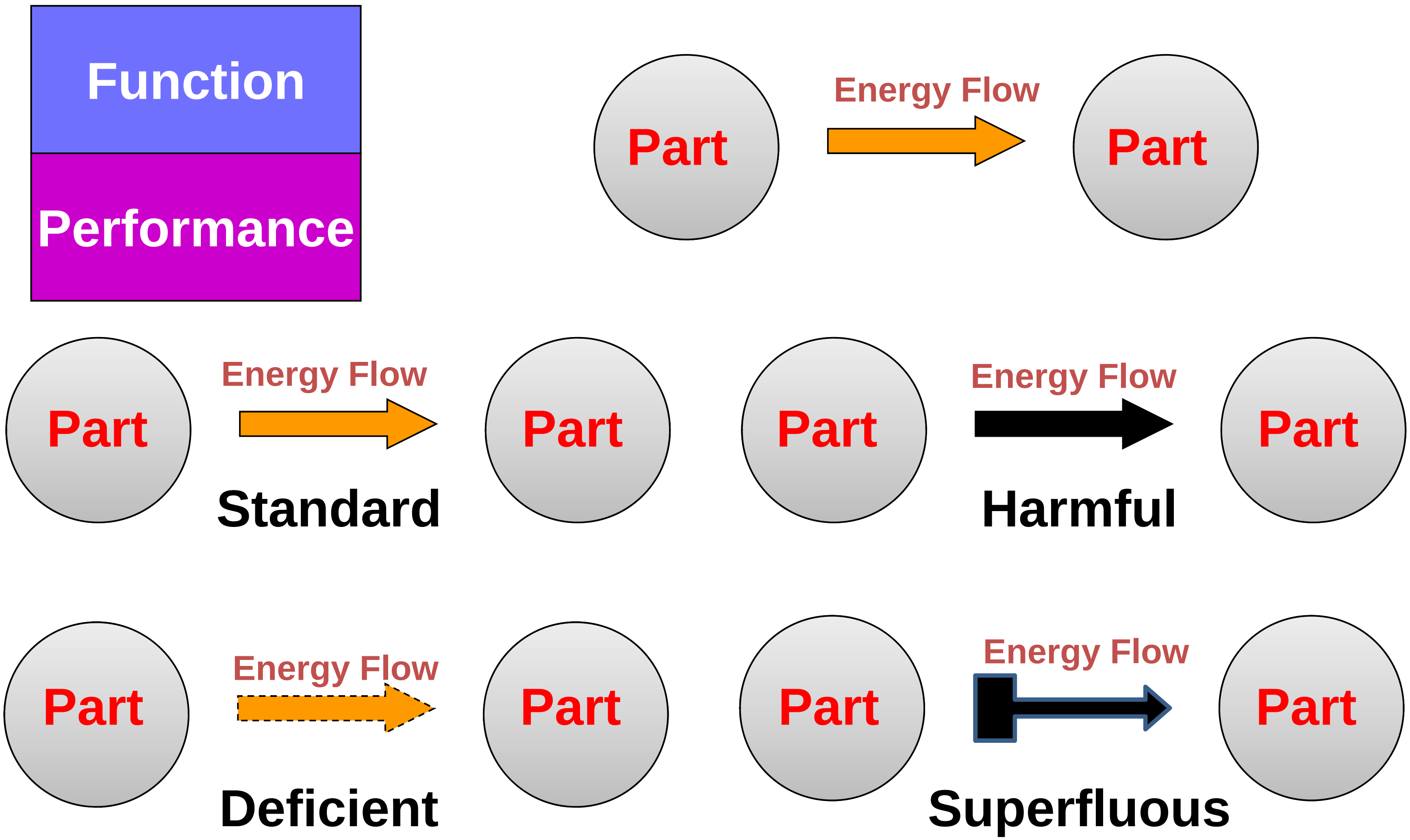
- **Output of three major energy-consuming products**



Background Energy Security and Energy Crisis

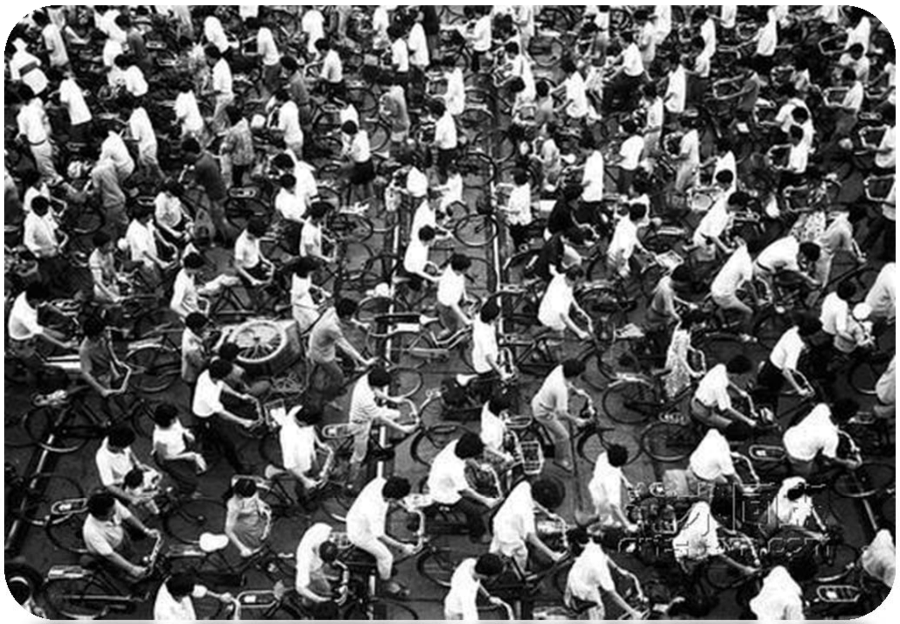
- **Problem**
  - **According to statistics of CMEMA (China Machinery Enterprise Management Association), 21 major industrial products consumed 70% of the total energy production.**
  - **Design for energy and material saving becomes a research focus for these years.**

Energy flow modeling



Product Design Based on Energy Flow

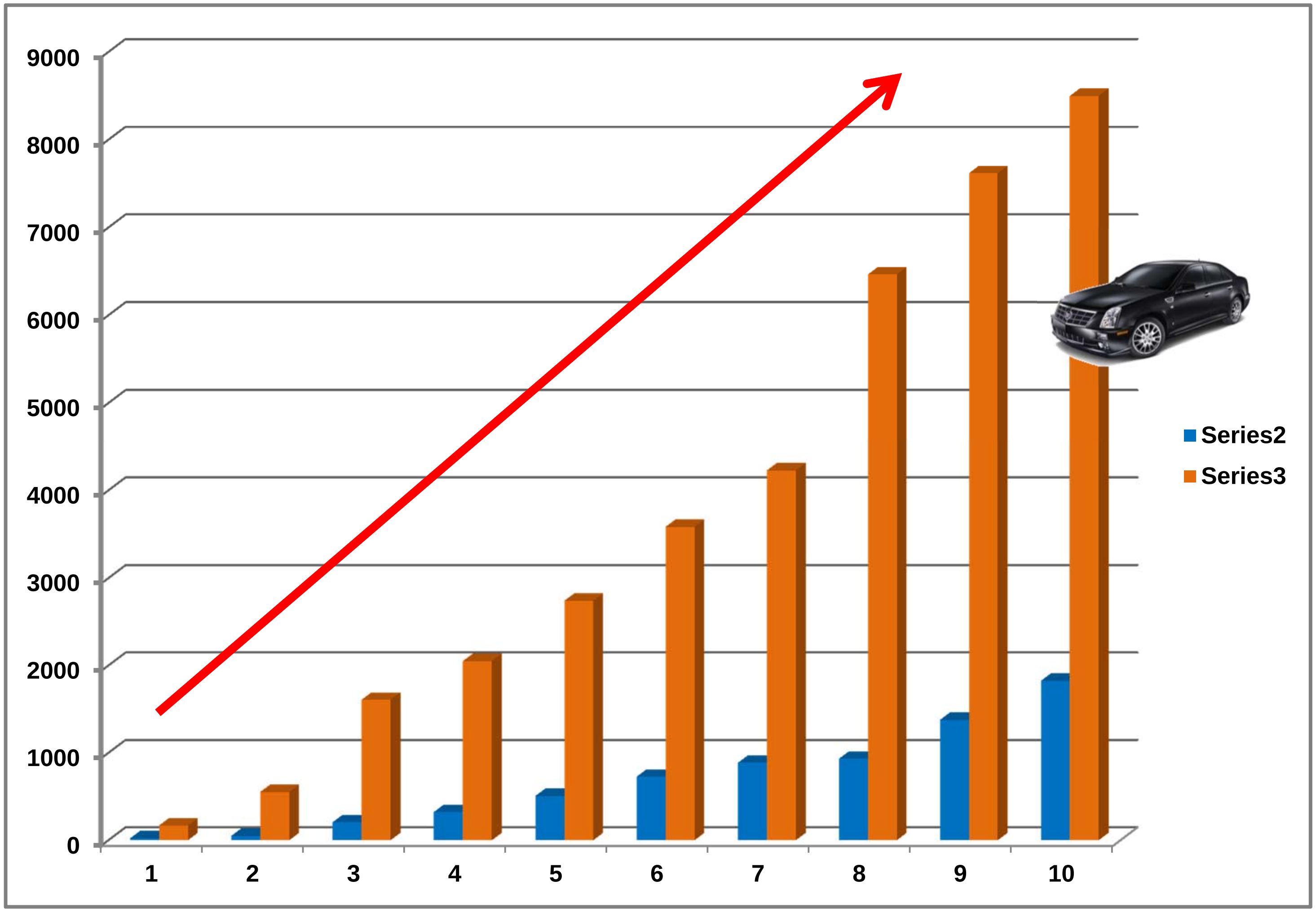
Transportation evolution:



From Bicycle Kingdom to Auto Kingdom

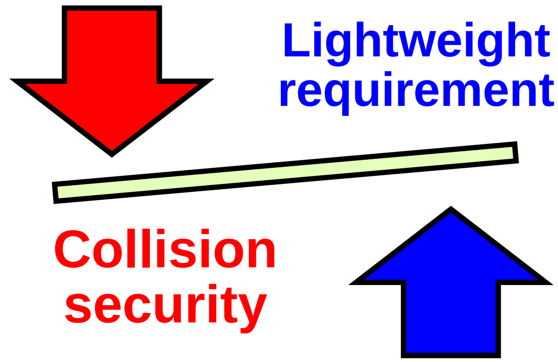
Instance

Product Design Based on Energy Flow



Product Design Based on Energy Flow

Conflict



SUV

Modeling of SUV Frontal collision

$$\Omega_{PC2} = \langle S_{p2}, \quad P_2 \rangle$$

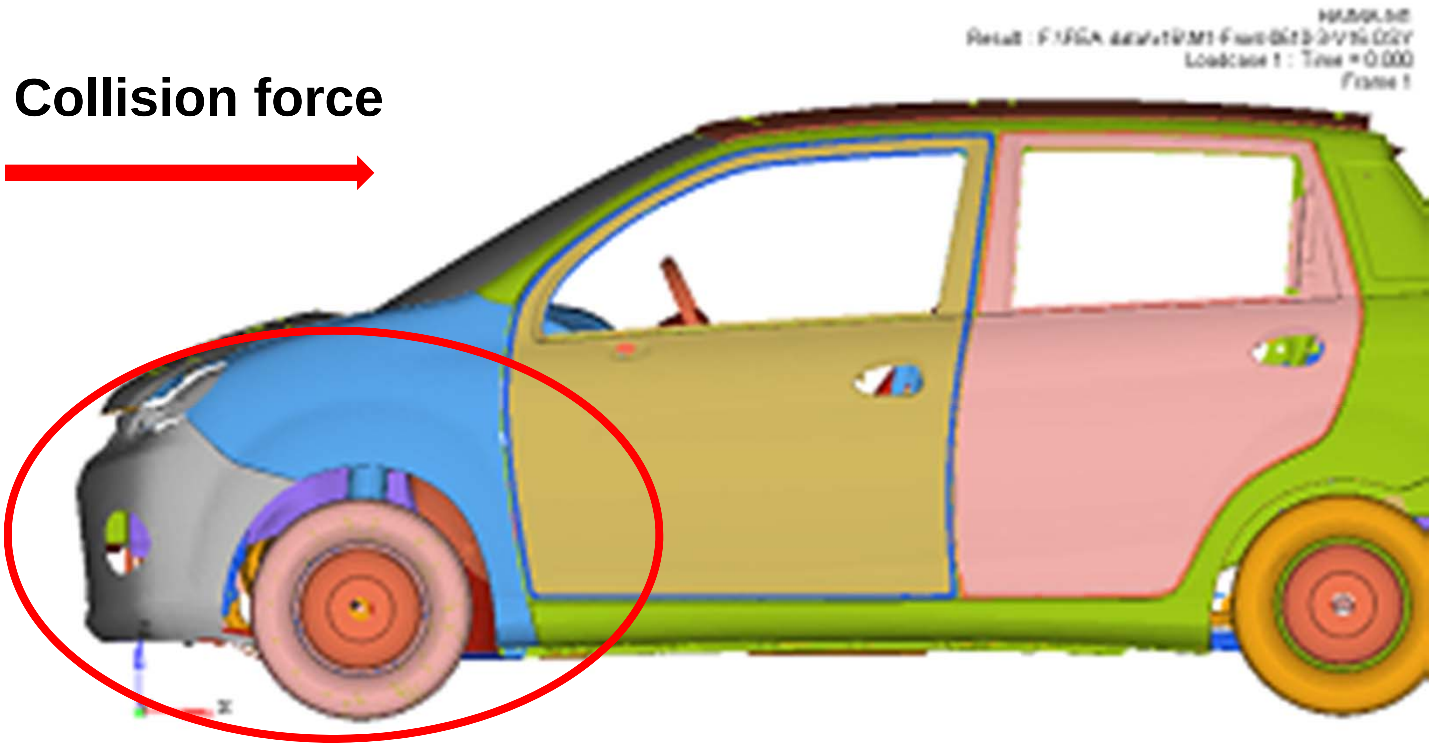
S_{p2} **Object: lightweight design for energy saving**

P_2 **Object: Passive security under frontal collision**

Ω_{PC2} **Realizing lightweight without lowering passive security**

■ Lightweight Design Based on Passive safety

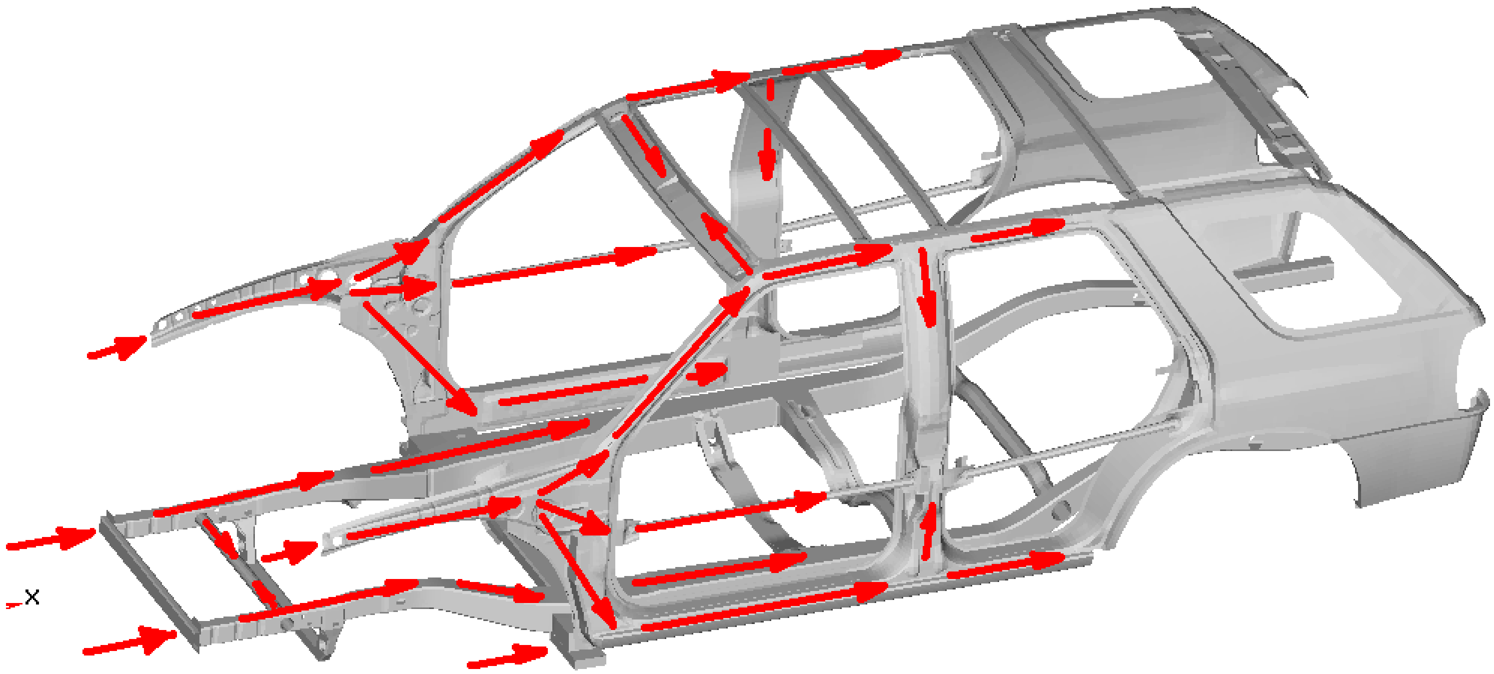
A: Collision force

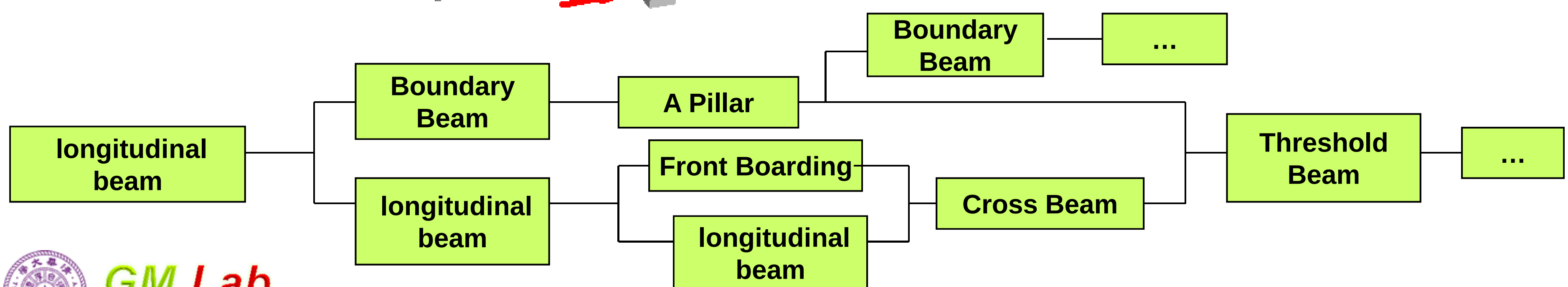


R: Deformation or fracture of components and parts

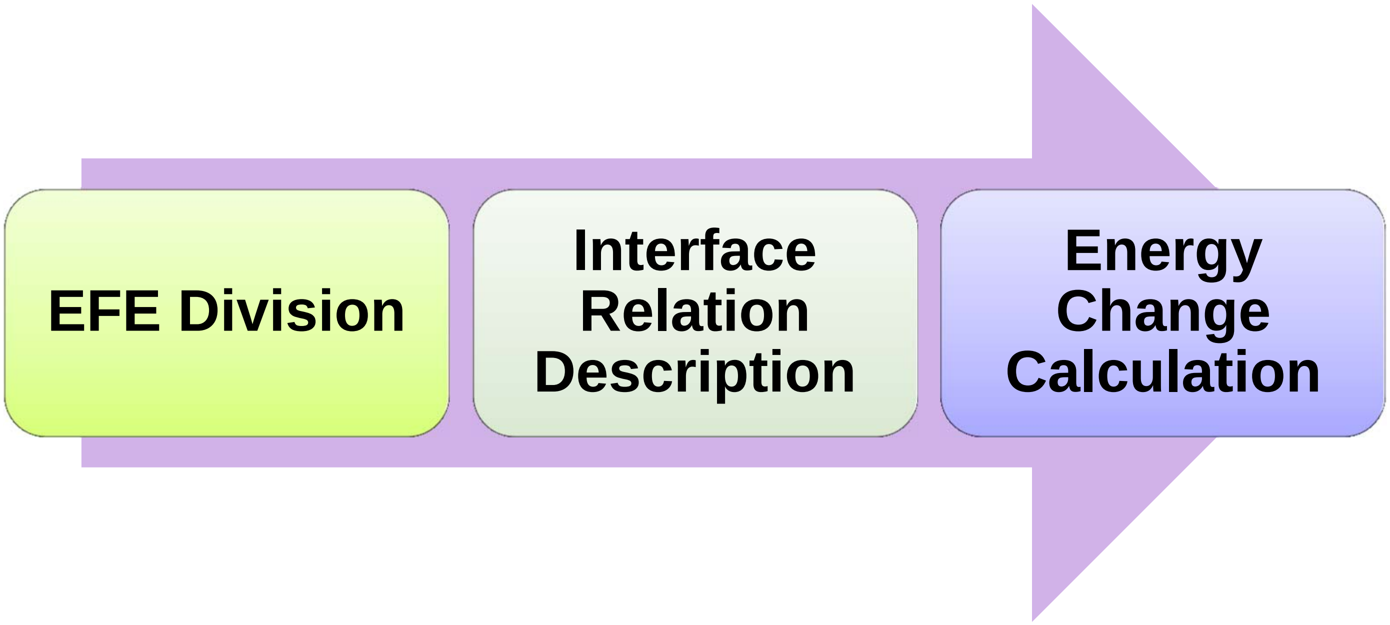
Product Design Based on Energy Flow

■ Energy flowing process





Definition of Energy Flow Element (EFE)



$$EFE = (D, \quad T, \quad \Delta E)$$

- D : Collection of components and parts in EFEs;
- T : Interface relations among EFEs;
- ΔE : Energy change during performance realization;

EFE Division

Reduction of Components in EFE

- Performance Related
- Functional independence

Generation of Design Structure Matrix

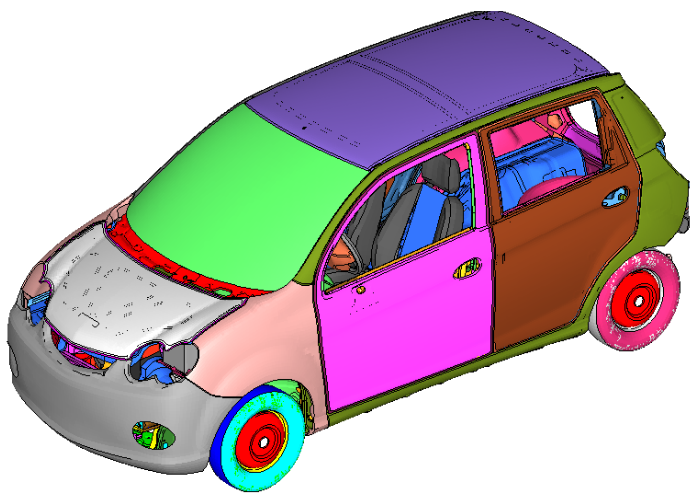
- Connection matrix
- Shape and position matrix
- Energy correlation matrix

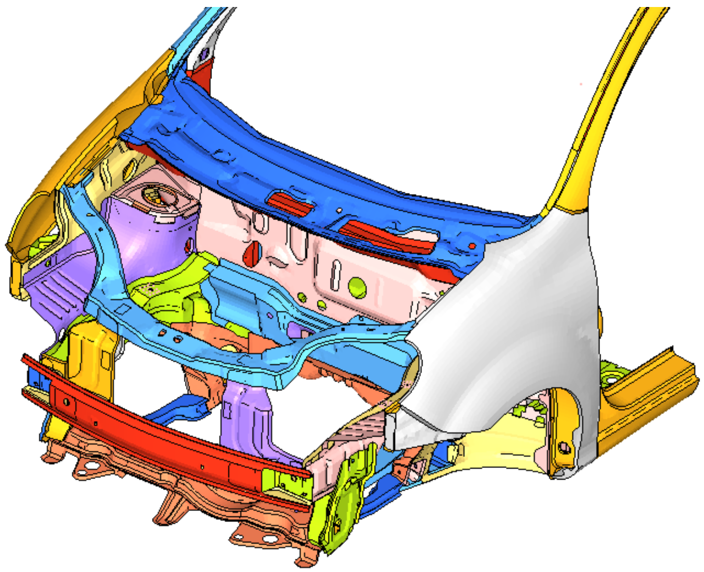
Solving of Fuzzy Graph

Determination of EFE Division

Product Design Based on Energy Flow

■ EFE Division Instance

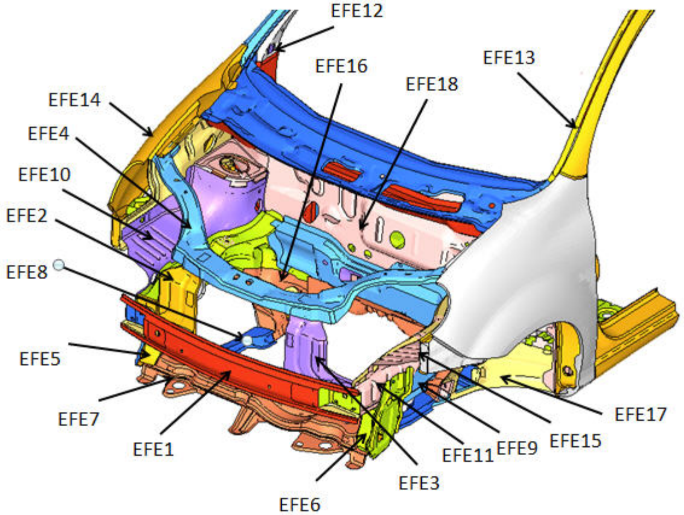




- **Components and parts reduced from 400 to 87**

Product Design Based on Energy Flow

■ EFE Division Results

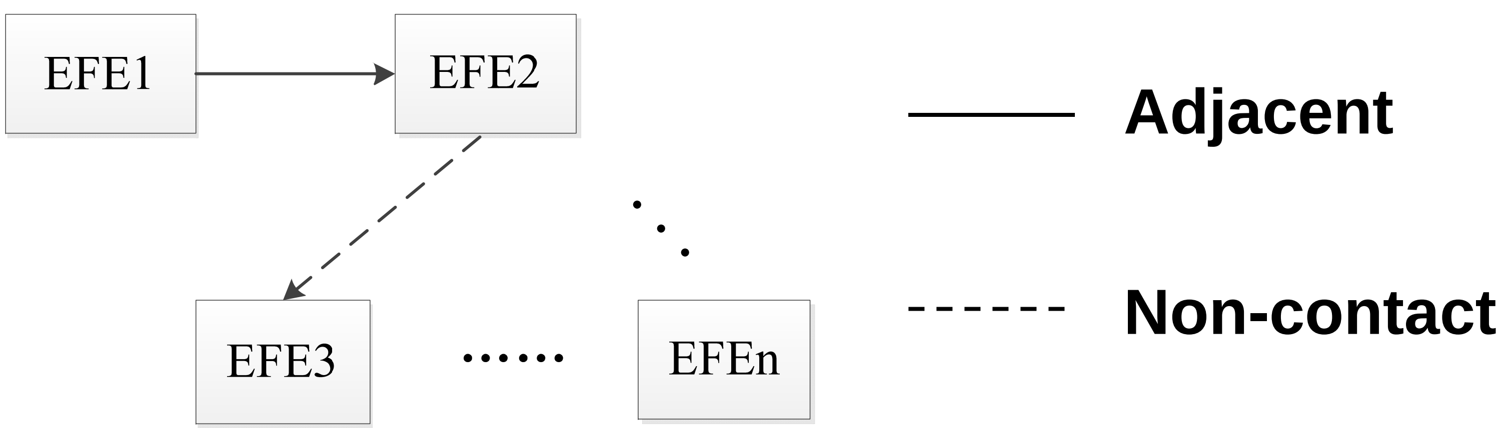


No.	Parts No. in EFE
EFE1	1,2,3,4,84
EFE2	5,6
EFE3	38,39
EFE4	7
EFE5	12,25,26
EFE6	44,54,55
EFE7	78,79,81
EFE8	82,83
EFE9	80,87
EFE10	8,21,24,27
EFE11	40,53,56,57
EFE12	37,61-64,66-69
EFE13	60,70-72,74-77
EFE14	13,14,65,85
EFE15	45,46,73,86
EFE16	11,15,16,19,20,22,23,28,35,36
EFE17	35,36,43,47-52,58
EFE18	9,10,17,18,29-34,41,42,59

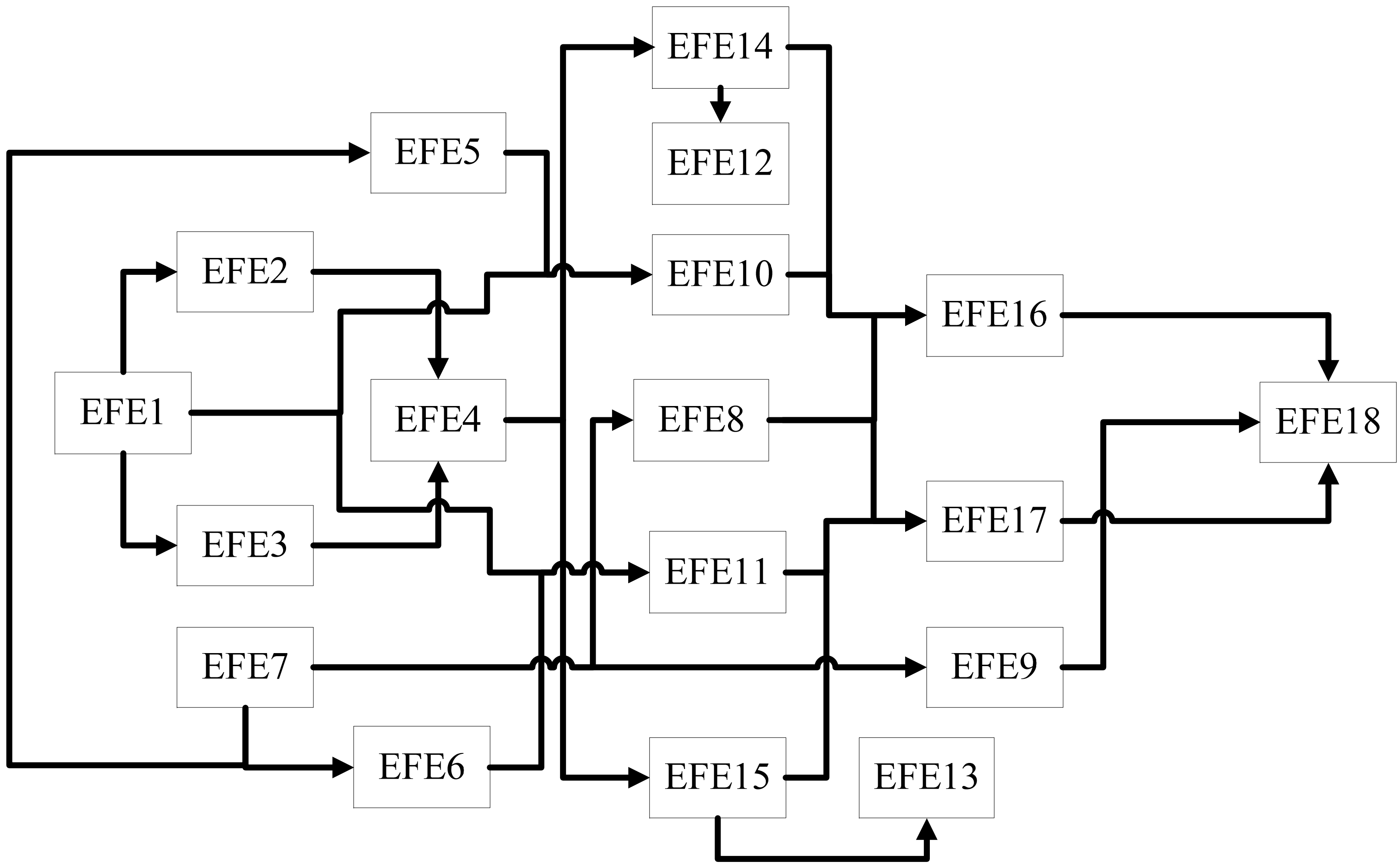
EFE interface relation

$$T = \left[\left(NO_i,\quad ST_i,\quad A_i\right)\right]_N$$

- NO_i : Relation between current EFE with i[th] EFE, 1 or 0 ;
- ST_i : Interface status, 1 or 0;
- A : Action form, , 1 or 0;

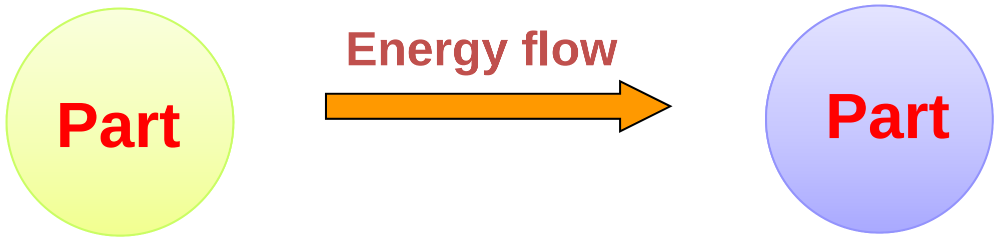


- **EFE Interface relation of automobile at Frontal collision**



Instance

Product Design Based on Energy Flow



- **Quantify the impact on energy flow when parts changes**

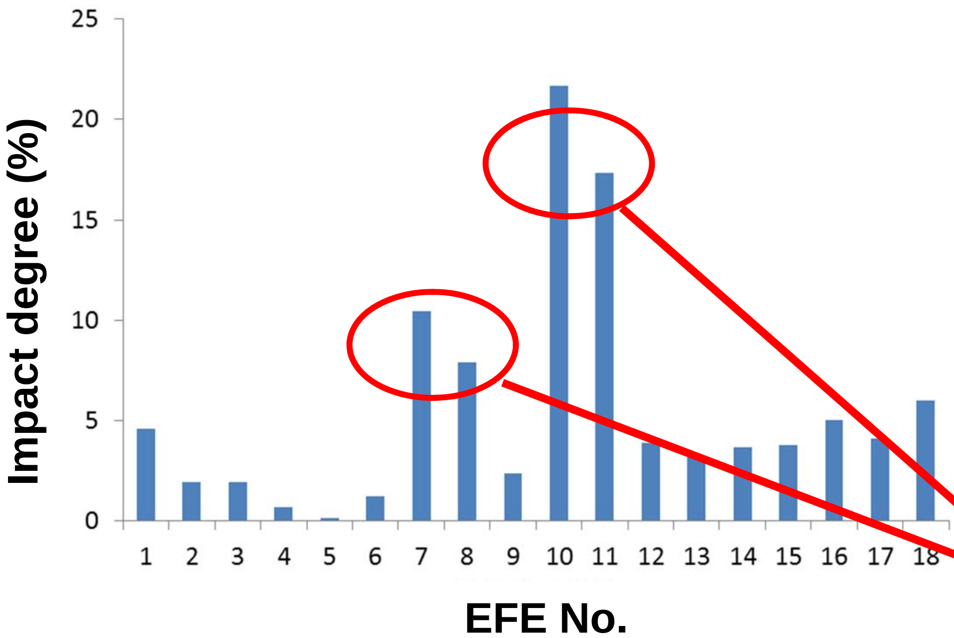
Performance Pertinences

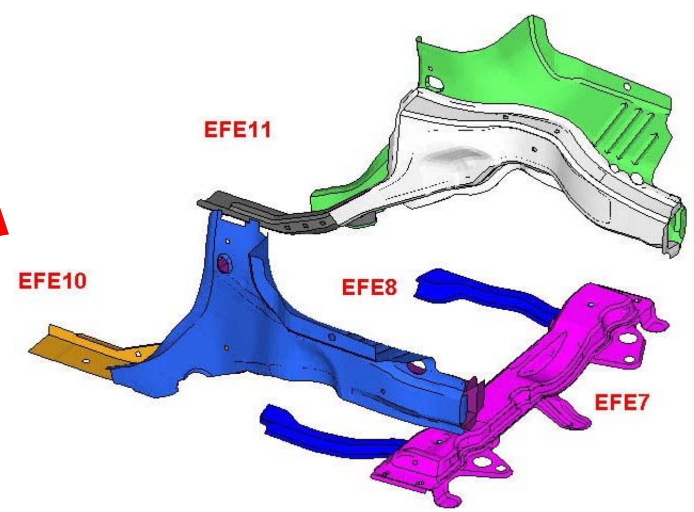
- **Quantify the rationality of energy flows between different parts**

Performance Margins

■ Performance Pertinences

- **The impact degree of part parameters changing on the change of energy.**





Performance Margins

- **The deviation between energy changing and ideal expected value.**

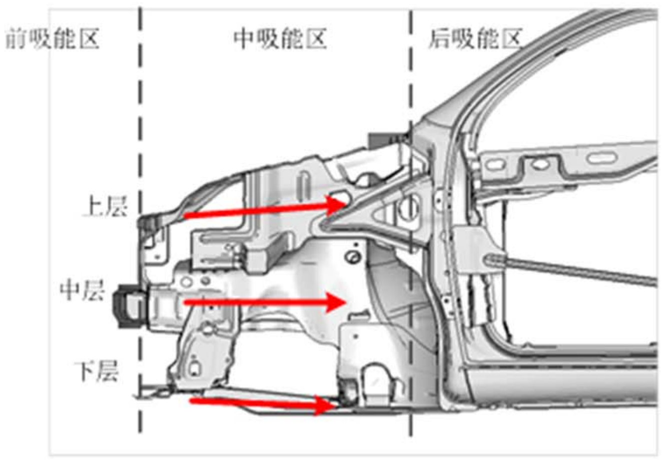
$$P_\eta = \eta \times \left(\zeta_{\Delta e} - E\left(\zeta_{\Delta e}\right)\right)$$

P_η	**Performance margins of parts**
$\zeta_{\Delta e}$	**Allocation ration of energy changing**
$E\left(\zeta_{\Delta e}\right)$	**Expected value of ideal distribution**

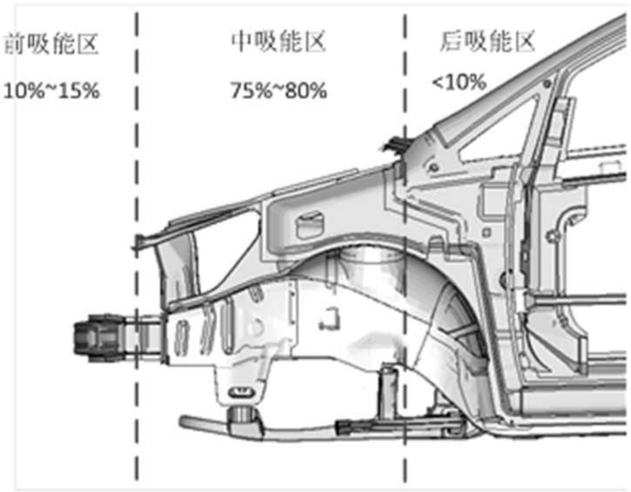
Definition

Product Design Based on Energy Flow

■ Calculation results of performance margins

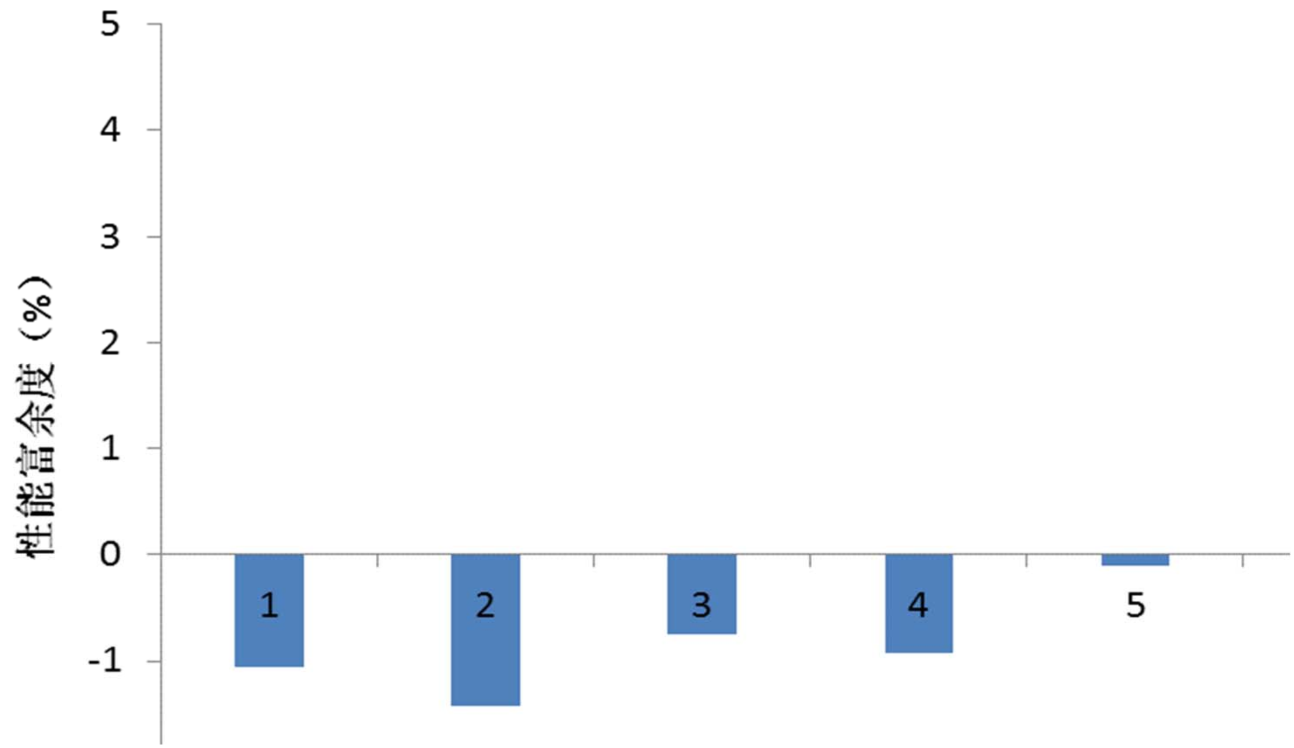


Current automobile



Referenced automobile

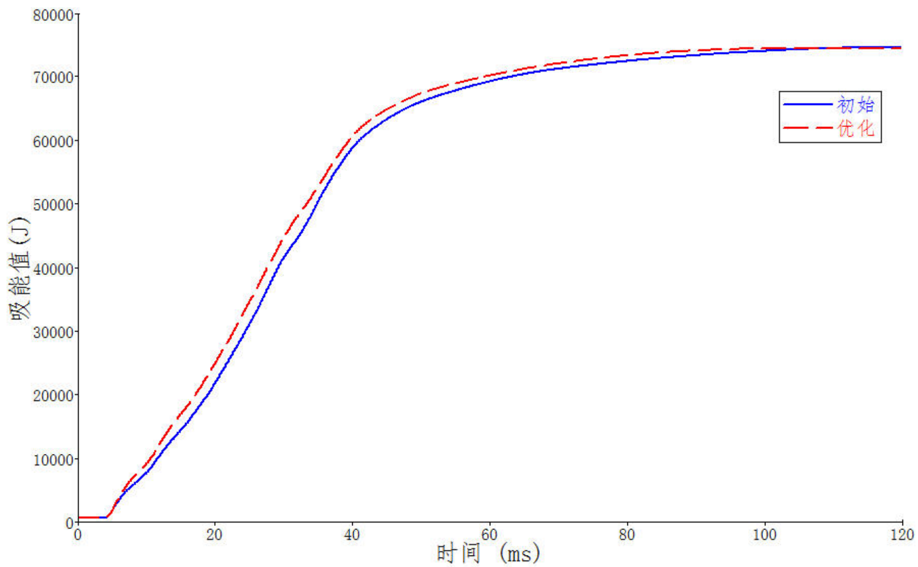
■ Performance Margins: Results



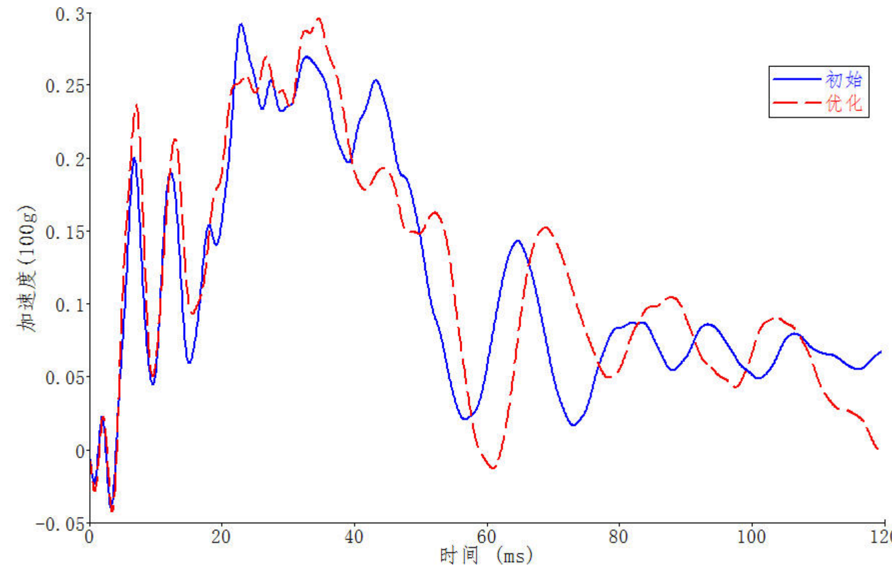
EFE1-4: potential parts for lightweight design

Product Design Based on Energy Flow

■ Results of optimization



Energy absorbing



Changing of accelerated speed

- **Weight (Longitudinal and its accessories) reduced from 32.64kg to 30.92kg (5.3%)**

Comparison of Crush Test

Unimproved Frame

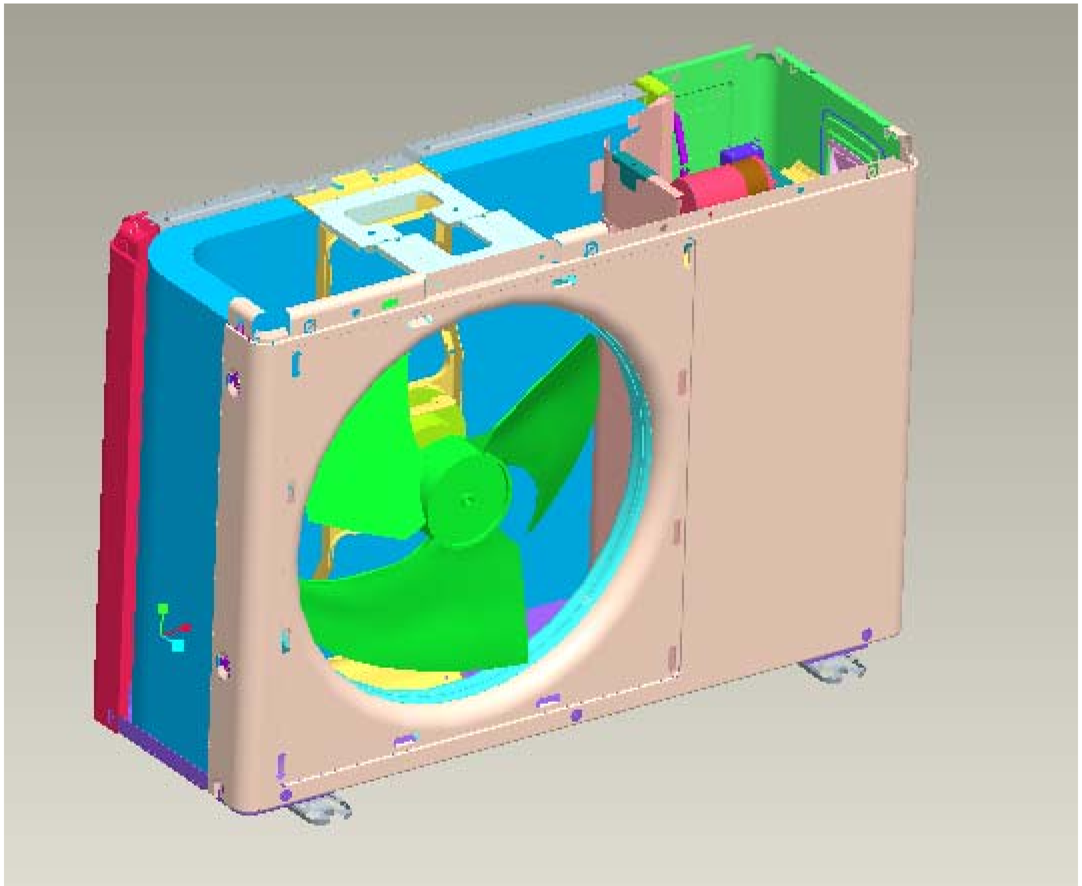
NCAP:★★☆

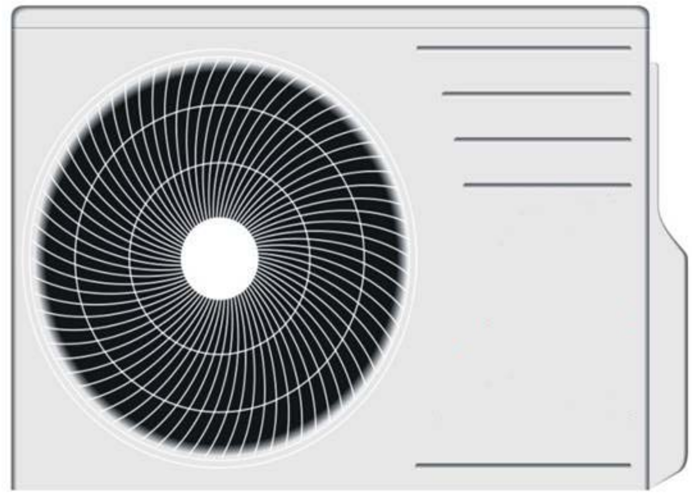
Improved Frame

NCAP:★★★★

Product Design Based on Energy Flow

■ Typical Application – Air Conditioner



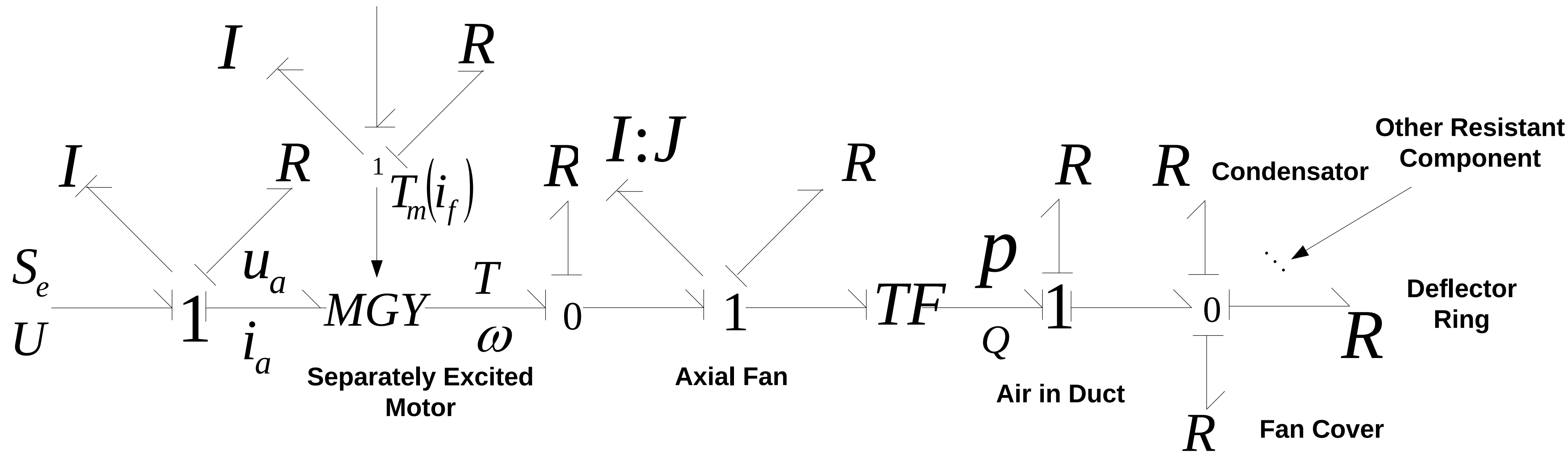


Design Objective

- Energy Saving
- Noise Reduction

Product Design Based on Energy Flow

Energy Flowing Model of Air Duct System



R : Resistant Compoent I : Inertial Component

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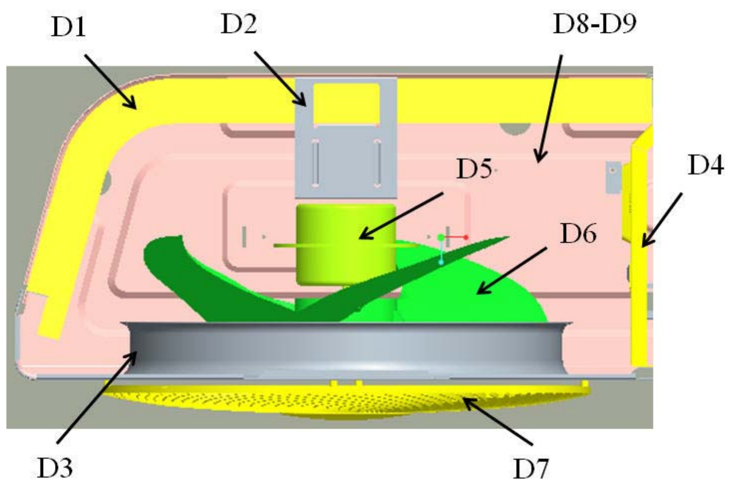
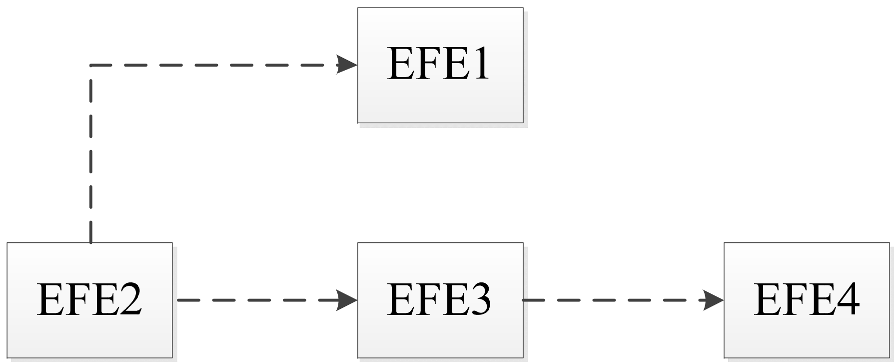
Product Design Based on Energy Flow

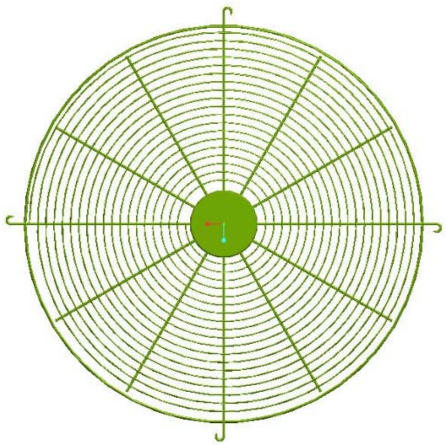
■ EFE Division

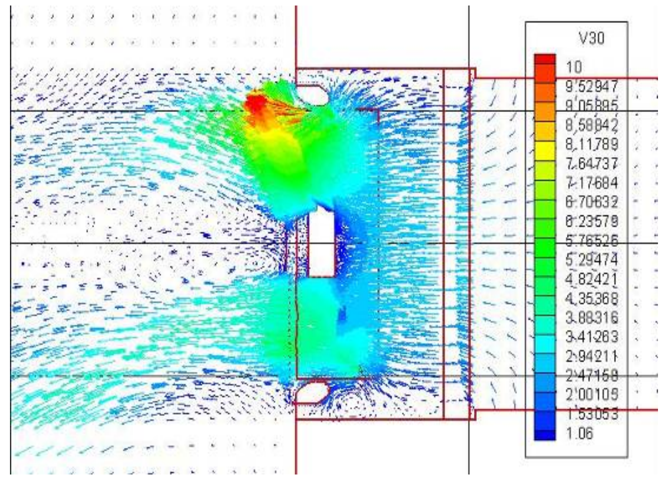


No.	Parts No. in EFE
EFE1	D1
EFE2	D2, D5, D6
EFE3	D3, D4, D8, D9
EFE4	D7



■ Comparison of Crush Test





Model	Performance indicators				
	rotation rate	Power	Actual airflow	Theoretical airflow	Noise
Original	800rpm	70w	1640m³/h	1710m³/h	51dB(A)
Optimized	800rpm	70w	1718m3/h	1794m³/h	49.8dB(A)

Reliability Design Based on Energy Flow

Reliability Design based on Energy Flow

National strategy

- *Long-term Development Planning for Renewable Energy*
- *National long-term Scientific and Technological Development*

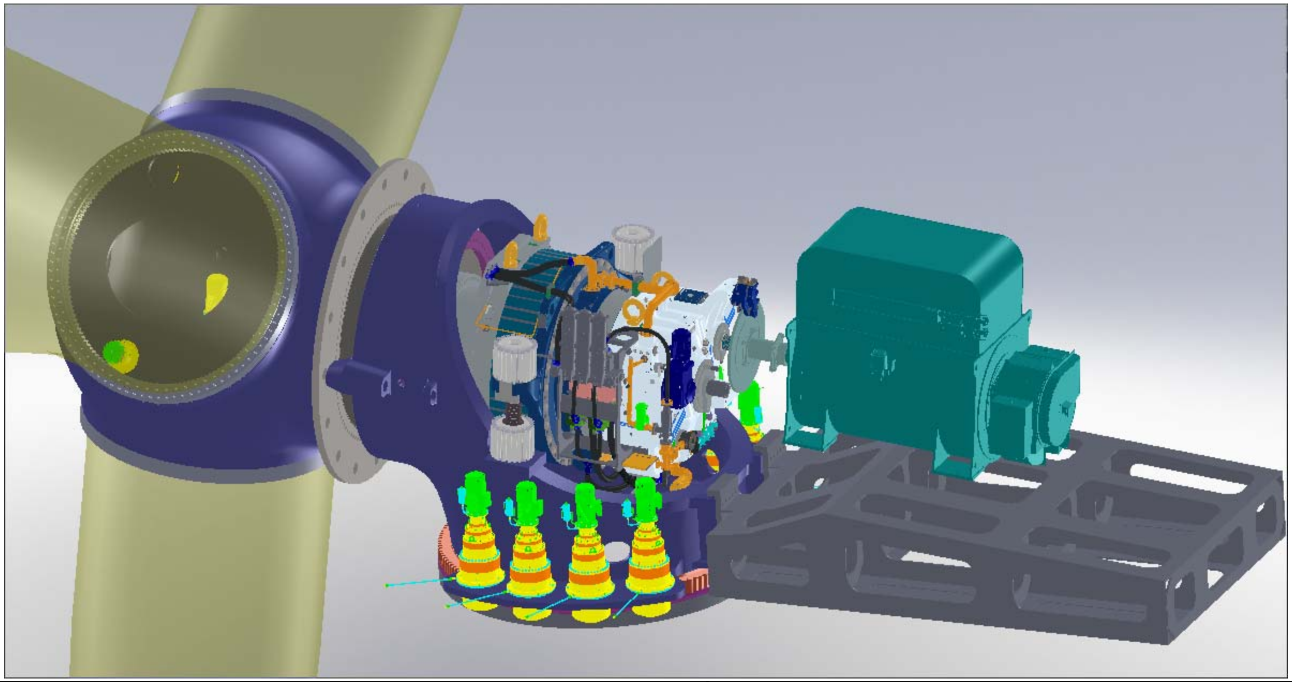
Rapid development of wind power industry

- **Available wind energy resources: 2.4 billion KW;**
- **New installed wind turbine in 2011: 18GW (40% of the world) and the total installed capacity have reached to 62.7 GW;**
- **7 new planed 10 million kw-level wind farm are under construction and the total investment exceed 300 billion RMB;**

Wind Turbine

Reliability Design based on Energy Flow

Environment	High Standards	Complicated System
➢installation site ➢Heavy working condition	➢Service for 20 Years; ➢High reliability ➢Security	➢Hundreds of tons ➢Dozens of sub-system ➢Mechanical, electronical and material science



China	Abroad
3MW - level (Design and manufacturing) Service life Core components rely on imports	Design for 10-15-20 MW-level Service life improve to 25-40 years

Wind Turbine

Reliability Design based on Energy Flow

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Green Manufacturing Laboratory

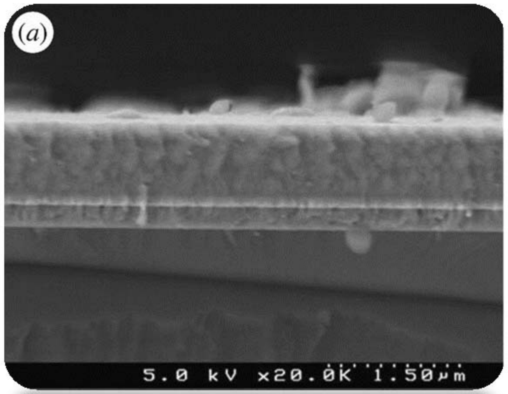
Tsinghua University, Beijing, China

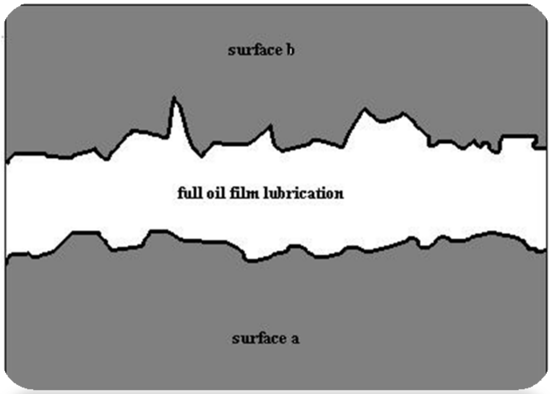
Degradation caused by complicated condition

Transmission system

- Frequent Low-speed start
- Alternating high and low temperature
- Impact load
- Low speed and heavy load

Performance degradation

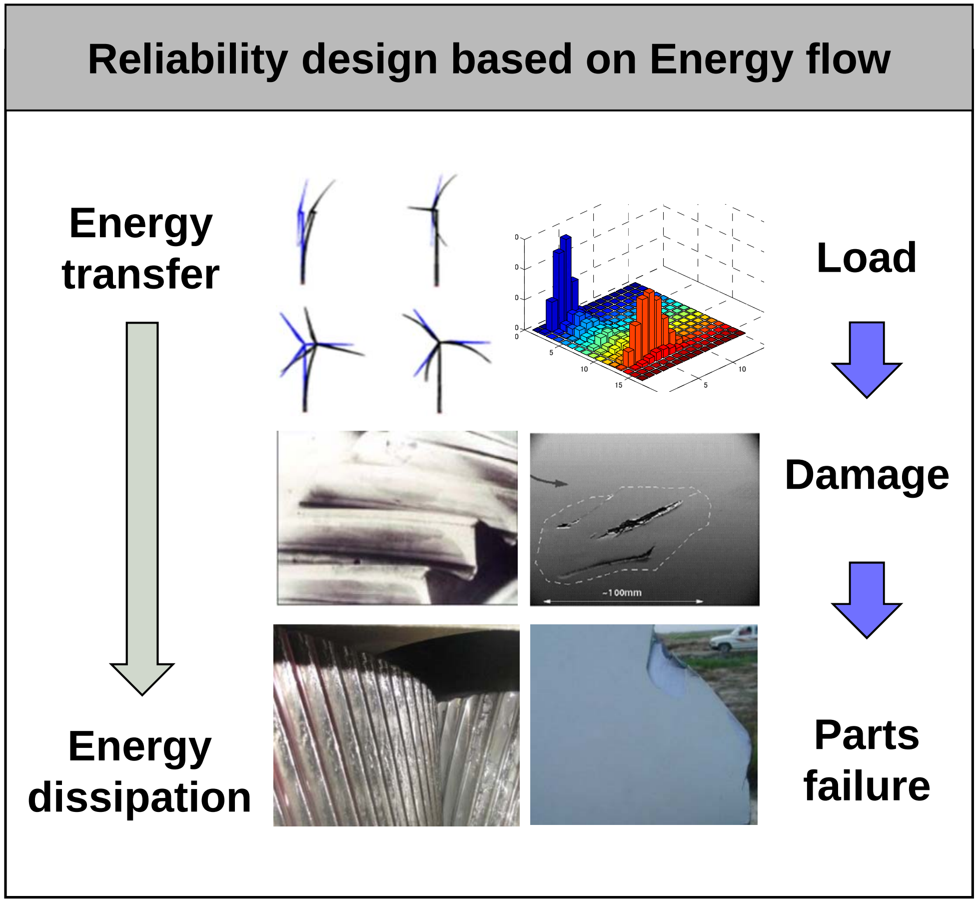




Interface layer

Reliability Design based on Energy Flow

■ Failure evolution and reliability

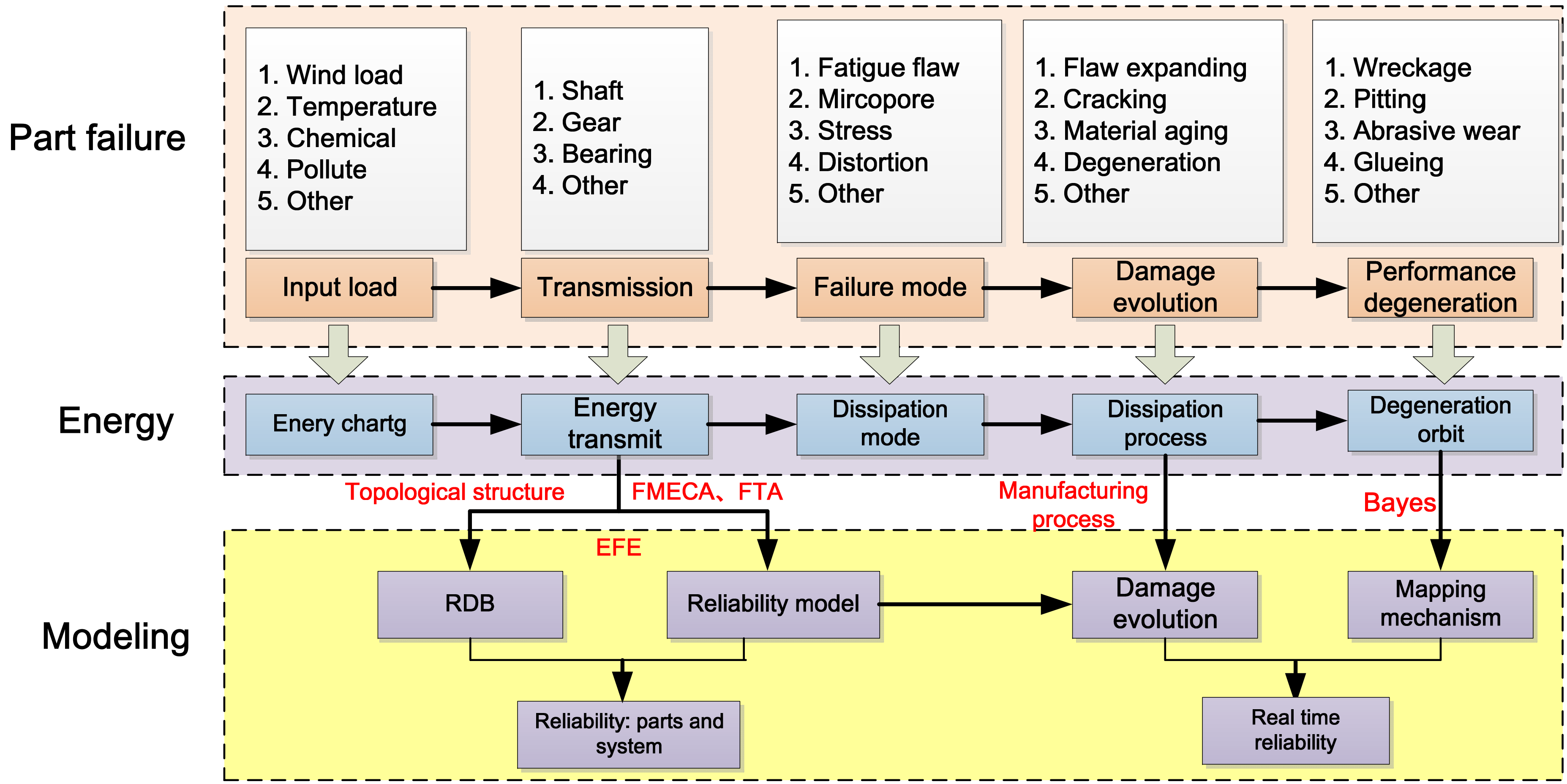


Analyzing in energy field:

- **Macroscopic: transfer and convert mechanical energy**
- **Microscopic: a dissipation process of energy**

Reliability Design Based on Energy Flow

■ Technical Route



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机械工程系 绿色制造实验室

Department of Mechanical Engineering

Thank you for your attention!

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