Life Cycle Analysis for xEV

—Energy Consumption and CO_2 Emission Evaluation Method

1.Why we need LCA?

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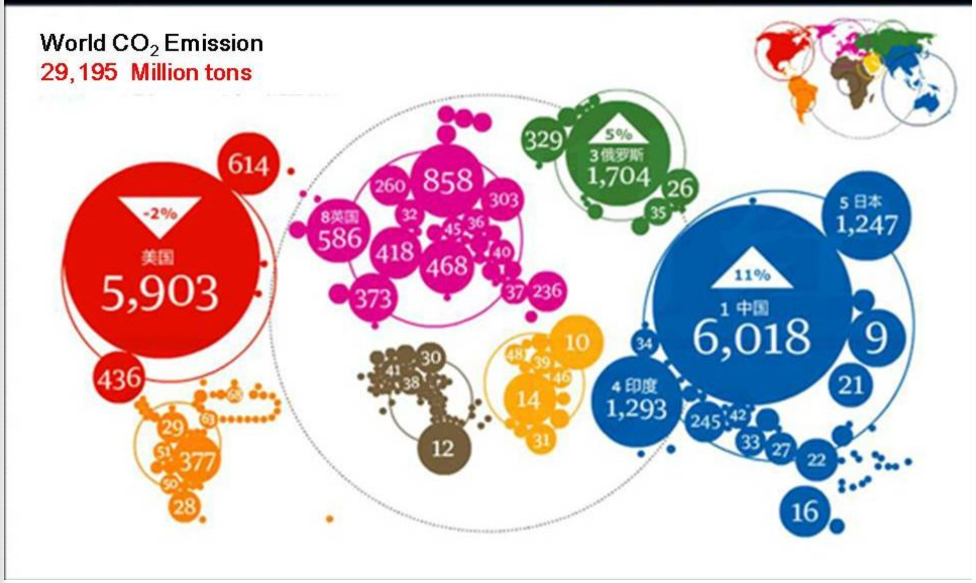
2008 World CO_2 Emission Map (Unit：million tons)

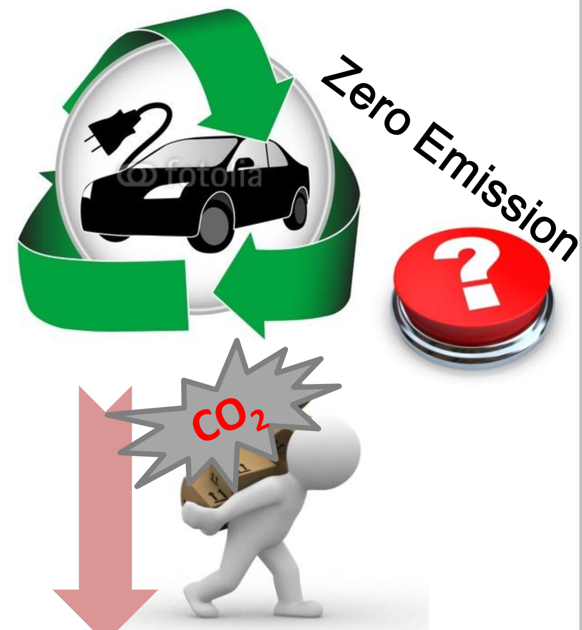
Sources：《EIA-2008 The prediction of international energy》



Composition of Beijing Pollutant Sources in 2008（%）

Pollutant Sources	NO_X	PM_{10}	HC
Power Plant	8	2	5
Building Materials	10	45	2
Chemical Industry	1	4	1
Smeltery	1	14	1
Industrial Boiler	14	15	11
Automobile	66	20	79

xEV= Energy Saving or GHG Reduction ?



Consensus and Principals

Principals

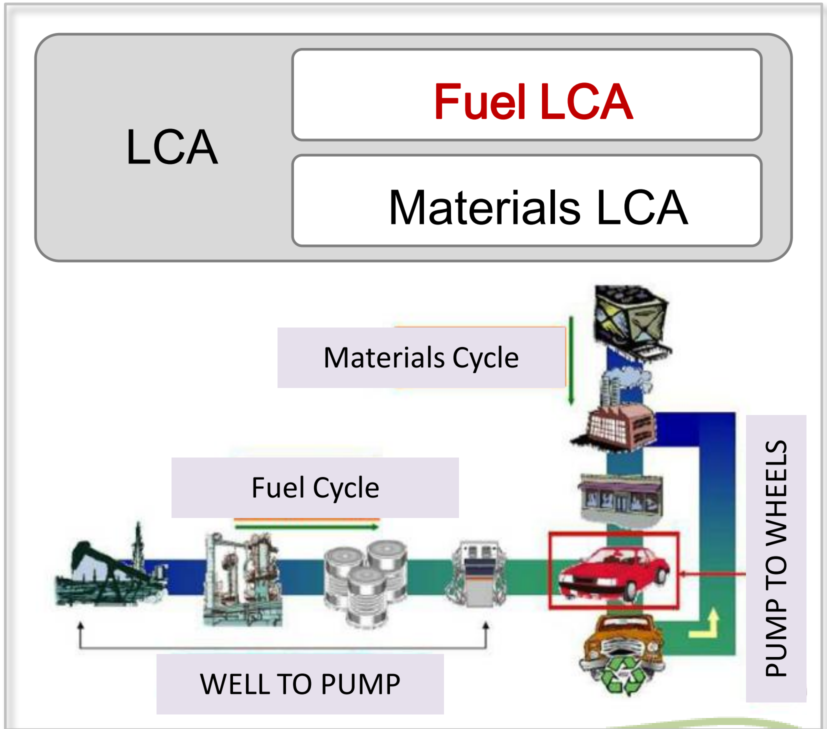
1. Thorough and objective evaluation on energy consumption during the whole life-span of EVs;
2. Convenient to compare energy consumption of EVs with vehicles fueled by conventional gasoline and diesel;
3. Convenient for the authority to take phase-in measures at different levels.

Consensus

1. Energy consumption of EVs should be measured and evaluated based on life cycle.
2. Power generation mix has an important impact of energy consumption of EVs
3. EVs do not promise much benefit in reducing CO_2 emissions currently
4. Each part of the value chain must be responsible for its relevant part – improper to shift all responsibilities to vehicle manufacturers

2. What's LCA?

Life-cycle assessment (**LCA**, also known as **life-cycle analysis**) is a technique to assess environmental impacts associated with all the stages of a product's life from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling).



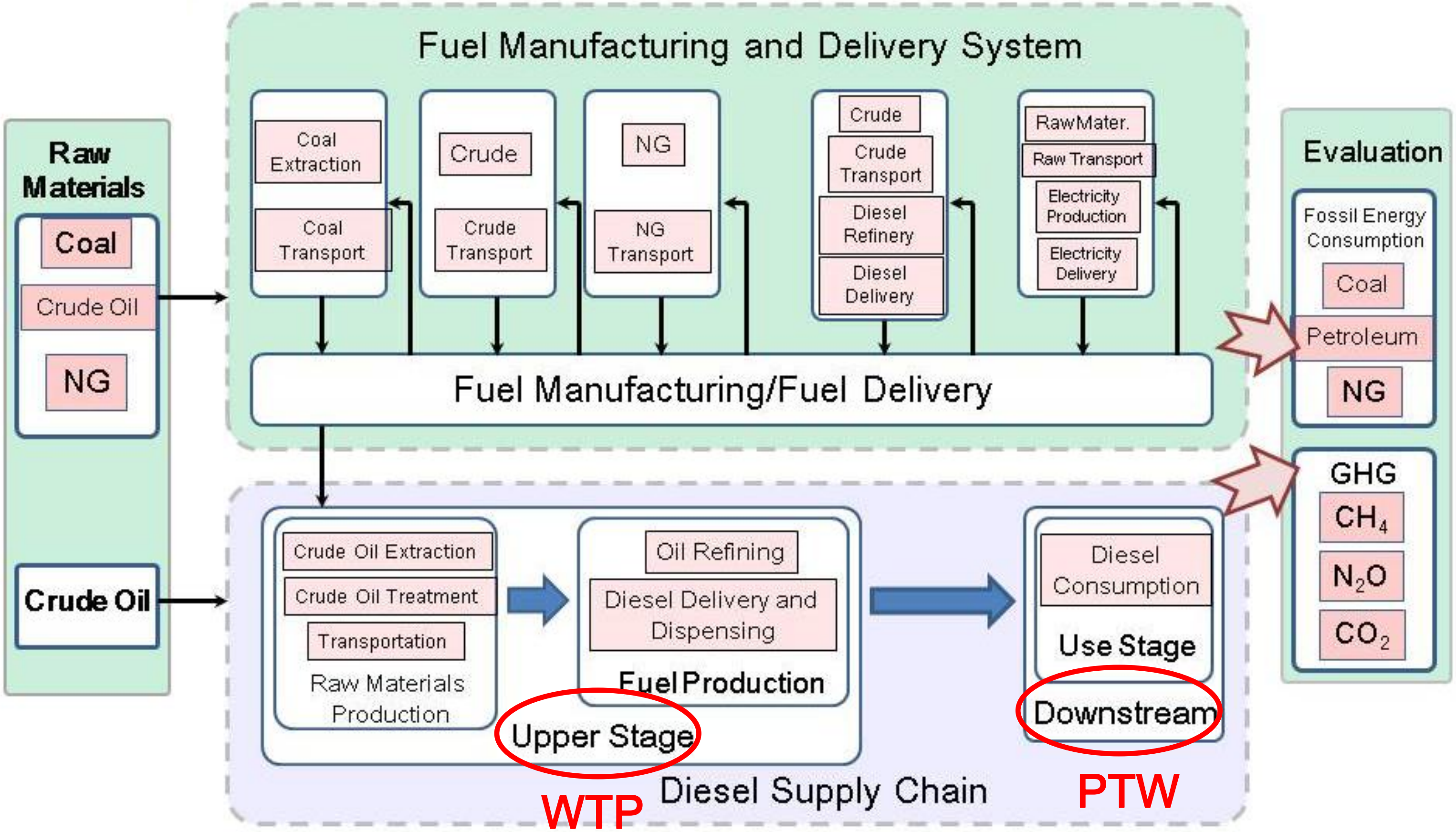
Features of LCA :

(1) It's a whole process evaluation regarding to raw materials collection, processing, production, usage, consuming, recycling and waste treatment—the life span of product;

(2) It's a systematic evaluation to study the influences to environment of product in its life;

3. Vehicle Fuel LCA (WTW)

Life-cycle analysis (LCA) of vehicle-fuel pathways covering the stages of resource extraction, fuel production, and utilization is conducted to examine the macro impact of energy supply and related greenhouse gas (GHG) emissions.



LCA for Vehicle Fuel （Diesel as example）

4. WTW Analysis in China

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The well-to-wheel variant has a significant input on a model developed by the Argonne National Laboratory. **The Greenhouse gases, Regulated Emissions, and Energy use in Transportation (GREET)** model was developed to evaluate the impacts of new fuels and vehicle technologies.

Based on the GREET model, the Tsinghua China automotive energy LCA Model (TLCAM) was constructed.

- Designed as a computing platform;
- Well to pump (WTP) and pump to wheels (PTW) are two independent stage;

4. WTW Analysis in China

To calculate the WTW results, the two functional units are linked through the fuel economy of the vehicle:

$$E_{\mathrm{WTW}} = E_{\mathrm{WTP}} * \mathrm{FE} + E_{\mathrm{PTW}}$$

$$\mathrm{GHG}_{\mathrm{WTW}} = \mathrm{GHG}_{\mathrm{WTP}} * \mathrm{FE} + \mathrm{GHG}_{\mathrm{PTW}}$$

where E_{WTW} *is the WTW primary fossil energy used per kilometer (MJ/km),* E_{WTP} is the WTP primary fossil energy and is used to show the WTP overall conversion efficiency (MJ/MJ fuel), FE is the vehicle-fuel economy (MJ/km), E_{PTW} *is the PTW* direct primary fossil energy used (MJ/km), GHG_{WTW} is the WTW GHG emission (g CO_2,e/km), GHG_{WTP} is the WTP GHG emission (g CO_2,e/MJ), and GHG_{PTW} is the PTW GHG emission (g CO_2,e/km).

4. WTW Analysis in China

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Main Steps of WTW Analysis

Step1: Goal and Scope Definition	Conducted to examine the macro impact of China's road transport energy supply and related greenhouse gas (GHG) emissions
Step2: Inventory Analysis	Basic Data Collection and Processing from Bureau of Statistics
Step3: Assumption for WTP	For different vehicle and fuel technology pathways, the fuel economy situation is assumed according to certain scenario
Step4: Getting WTP Results	The conversion efficiency of the WTP stage is defined as the ratio of the calorific value of the fuel to the total fossil energy input during the WTP stage (including the raw material input).
Step5: Getting WTW Results	Combine the WTP and PTW data to calculate WTP Results

Examples of Step 2 and 4 for WTW analysis

Basic parameters of oil-, and coal-based fuel pathways

Oil extraction
- Extraction efficiency, 93.0 %
- Process fuel mix: electricity (37 %), crude oil (20 %), NG (23 %), coal (10 %), diesel (8 %), residual oil (1 %), and gasoline (1 %)

Oil transportation mode
- Sea tanker, 50 % (11,000 km); rail, 45 % (950 km); pipeline, 80 % (500 km); and waterways, 10 % (250 km)

Oil refinery
- Process fuel mix: crude oil (50 %), coal (20 %), electricity (12 %), refinery still gas (10 %), residual oil (4 %), diesel (1 %), and gasoline (1 %)
- Gasoline production efficiency, 89.1 %; diesel production efficiency, 89.7 %; and LPG production efficiency, 92.0 %

Gasoline and diesel TSD mode
- Sea tanker, 25 % (7,000 km); railway, 50 % (900 km); waterways, 15 % (1,200 km); and road (short distance), 10 % (50 km)

LPG TSD mode
- Sea tanker, 30 % (7,000 km); railway, 80 % (900 km); pipeline, 0 % (160 km); waterways, 15 % (1,200 km); and road (short distance), 10 % (50 km)

NG extraction and processing
- Extraction efficiency, 96.00 %; process fuel mix for NG extraction: electricity (40 %), NG (23 %), residual oil (20 %), diesel (8 %), coal (7 %), and gasoline (2 %); NG processing efficiency, 94.00 %; and process fuel mix for NG processing: residual oil (40 %), NG (28 %), coal (20 %), electricity (10 %), diesel (1 %), and gasoline (1 %)

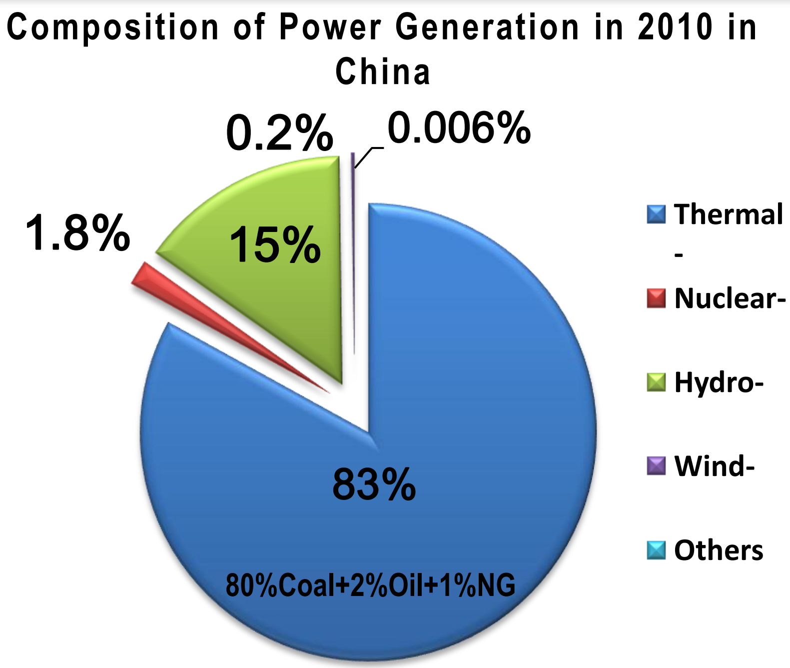
CNG, LNG, and GTL production
- CNG production efficiency, 96.9 %; LNG production efficiency, 90.2 %; and GTL production efficiency, 54.2 %

WTP results

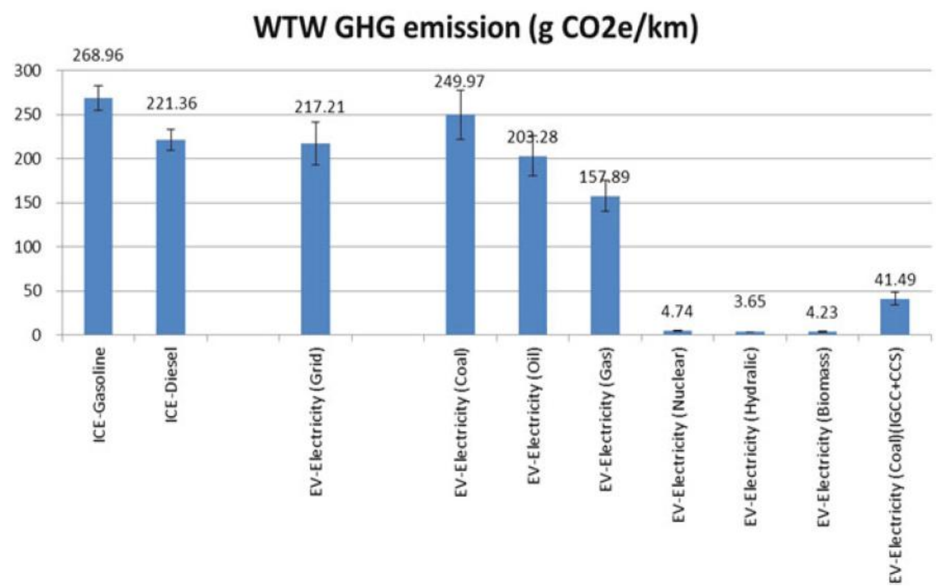
Pathway	Unit	WTP efficiency	Positive error	Negative error	Note
Part I: Fossil fuel as feedstock					
ICE-gasoline	%	73.60	3.68	3.68	Current situation; will not vary much in future
ICE-diesel	%	76.03	3.80	3.80	Current situation
ICE-LPG	%	78.84	3.94	3.94	Current situation
ICE-CNG	%	82.50	8.25	8.25	Current situation
ICE-LNG	%	78.99	3.95	3.95	Current situation
ICE-GTL	%	51.51	7.73	7.73	Current situation
ICE-MeOH	%	44.90	8.98	6.74	Current situation
ICE-DME (coal)	%	42.45	8.49	6.37	Current situation
ICE-CDL	%	44.99	6.75	4.50	Current situation
ICE-CTL	%	37.06	5.56	3.71	Current situation
ICE-MeOH (CCS)	%	35.30	8.83	7.06	When the technology is mature
ICE-DME (coal) (CCS)	%	35.00	8.75	7.00	When the technology is mature
ICE-CDL (CCS)	%	40.96	8.19	6.14	When the technology is mature
ICE-CTL (CCS)	%	33.24	6.65	4.99	When the technology is mature
EV-electricity (grid)	%	34.20	3.42	3.42	Current situation
EV-electricity (coal)	%	28.56	2.86	2.86	Current situation
EV-electricity (oil)	%	24.40	2.44	2.44	Current situation
EV-electricity (gas)	%	35.08	3.51	3.51	Current situation
EV-electricity (coal) (IGCC+CCS)	%	29.72	4.46	4.46	When the technology is mature

5. WTW Results for xEV

Electricity is not only an important energy input for other vehicle fuel pathways, but also be directly used as vehicle fuel to drive the EV and PHEV. The Grid electricity WTW result is an weight average of various power generation.



Sources： Chinese Federation of electric power enterprises ，2011



Sources：China Automotive Energy Outlook2012

Grid GHG=[249.97 * 0.8（Coal）+3.66*0.15 （Hydro）+。。。]/0.935=222.5 g $CO_{2,e}$/km

5. WTW Results for xEV

The Common Data for PTW evaluation:

WTW Energy consumption and CO_2 Emission for Vehicles with various fuels

	Energy Consumption (MJ/km)	CO_2Emission ($CO_{2,e}$/km)
ICE-Gasoline	3.42	268.96
ICE-Diesel	2.75	221.36
BEV (Grid)	2.13	217.21
FCV (Coal to H_2)	2.72	246.29

Conclusion for WTW in china

- From 2009~2012, China Automobile Energy Research Center of Tsinghua University, which was invested by SAIC and GM, carried out relevant researches on the correlation between energy development and economic, technology, environment. The result was published as " China's vehicle energy outlook 2012 “.

- These studies concern on the life cycle energy consumption and greenhouse gas emission assessment of various vehicle energy sources, setting up a general LCA model according to China energy structure.

- These studies give direct evidence for Chinese government to formulate environmental-friendly policies regarding to electric vehicles. Therefore, investigation and discussion on upstream power is necessary.

Comments on item 5.2

- We think it is very necessary to find the proper expression method for energy consumption.
- There is no carbon emission for electric vehicles during electric-driven process, however, carbon emission still exists in the process of raw materials exploitation and transportation as well as power production.
- The expression method for energy consumption should clarify the fuel saving effect for electric vehicles. Therefore, further investigation and discussion on upstream power is still needed.
- The study is very challenging due to varied power structure for each nation, however, it is also very meaningful for environment protection.

➢ To carry out the related research on 5.2, it is advisable to take the following steps:

Step1:

Study on the electric vehicle energy consumption evaluation method executed by main countries.

Step2:

Build database and conduct comparative analysis on the energy structure for main countries in the world.

Step3:

Discusses the necessity and possibility to standardize the energy consumption method.

Thanks!