LIFE CYCLE ASSESSMENT ON DIFFERENT TYPES OF ASPHALT RUBBER PAVEMENT IN CHINA

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ABSTRACT

The Ministry of Transportation of the People's Republic of China (CMOT) has a target of "establishing green, recycled, low carbon road" during the "Twelfth Five-Year Plan" (2010-2015). With that target, technologies with the characteristics of low carbon and recycling are widely used now in China for the construction and maintenance of asphalt pavement. Among them, asphalt rubber (AR) technology is recognized as a kind of perfect material with high performance and environmental advantages. In this research, the evaluation system of energy conservation and emission reduction of asphalt rubber pavement was established based on life cycle assessment (LCA). Through literature review and field investigation, the energy consumption of material production and pavement construction was obtained. The energy consumption and greenhouse gas (GHG) emission of hot mix asphalt (HMA) pavement as well as AR pavement were calculated. And the difference between them was also compared. Results show that, among the pavement construction phases, the mixing process consumes the most energy, while paving and compaction processes consume much less. The energy consumption of field blended asphalt rubber (FBAR) mixture is 5.75% lower than SBS modified asphalt mixture, and the terminal blended asphalt rubber (TBAR) and Trans-Polyoctenamer (TOR) mixture are 13.66% and 13.61% lower. The AR technology has significant advantage of energy conservation over the SBS modified asphalt pavement.

INTRODUCTION

Global energy shortage and climate changes have been the challenges of international society. The target of energy conservation and emission reduction needs cooperation by the international community. Asphalt rubber has been used in a certain scale both at home and abroad as a kind of environmental friendly material. Many researches and projects have proved that AR can improve pavement performance and prolong the service life. Pavement construction is an important part of transportation industry, and it consumes a large amount of energy *(1)*. The exploration of asphalt pavement energy consumption and GHG emission in European countries and North America began in the early 21st century. They have integrated the concept of LCA with life cycle cost assessment (LCCA). The energy consumption and GHG emission during the asphalt pavement life cycle were calculated *(2-7)*. And part of the foundation database was established, and relevant calculation software was developed. Some domestic scholars have carried out some researches on the calculation of energy consumption and GHG emission during the process of road construction and maintenance *(8-10)*. However the life cycle assessment on asphalt pavement in China is at the initial stage. The evaluation system and LCA database for China has not been established so far. Against this background, this research focuses on life cycle assessment on AR and HMA pavement, and establishing the LCA database or life cycle inventory (LCI) for China. It will provide the basis and methodology for the evaluation of energy conservation and GHG emission between AR and HMA pavement.

METHODOLOGY

Evaluation Index

In order to evaluate the environmental benefits of asphalt rubber pavement construction, the indexes including energy consumption and GHG emission are selected for energy conservation and emission reduction as well as recycling utilization with the consideration of resource conservation and construction waste recycling. Therefore, the evaluation index system includes the following indicators:

1. Energy consumption: (unit: $MJ \cdot t^{-1}$), this indicator embodies the energy consumption of the materials production and road construction, while the feedstock energy of the materials are excluded. The energy consumption data during the construction including electricity, diesel, heavy oil, natural gas, etc were collected, and then converted to the unified energy unit according to the conversion coefficients in China Energy Statistical Yearbook (2011 edition).
2. GHG emission: (unit: $kg \cdot t^{-1}$), the indicator embodies the greenhouse gas emissions produced by various types of energy consumed. The GHG mainly includes carbon dioxide (CO_2), methane (CH_4), nitrous-oxide (N_2O). They were converted to equivalent CO_2 emission in terms of global warming potential (GWP) from IPCC 2006 *(11)*; the conversion coefficients of CH_4 and N_2O were 25 and 298 respectively.
3. Recycling utilization: (unit: $kg \cdot t^{-1}$), the indicator reflects the natural resources conservation and construction waste recycling. Only the energy consumption and GHG emission are insufficient to embody the advantage of materials recycling and the value of natural resources. The materials recycled were calculated for evaluating the technology. For example the scrap tire rubber powder was reused in AR pavement, and the reclaimed asphalt pavement can be reused by the recycling technologies.

Boundary Condition of Calculation

As the study mainly focuses on the difference between various asphalt rubber, meanwhile there is not adequate data and calculation models for service life of pavement at present, only the processes directly related to pavement construction are analyzed in this paper, including the production and transportation of asphalt, aggregate and other raw materials, mixing and paving. While the indirectly related processes as infrastructure construction, production of machines and service life of pavement are excluded. Besides, for reasons of practicality and feasibility, a cut-off criterion suggested by ISO is used in this research. The cut-off criterion is based on the environmental impact and the 1% threshold is commonly used. When the inputs that estimated to contribute less than 1% to the overall environmental impact of the product, they are excluded. Figure 1 shows the system boundary analyzed in this research.

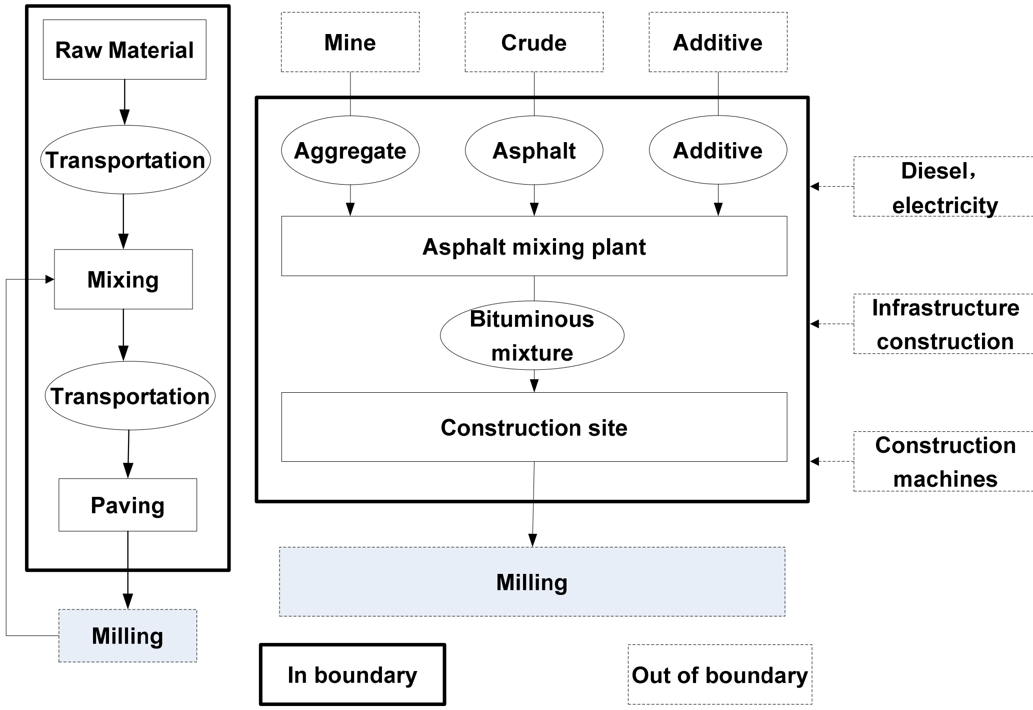

Figure 1: System boundary of LCA for asphalt pavement in this research.

PRODUCTION OF RAW MATERIALS

The raw materials of asphalt pavement include aggregate and asphalt. The energy consumption and GHG emission of aggregate refers to Chinese Life Cycle Database (CLCD) *(12)*. The database of European Bitumen Association provides the basic LCI data for virgin asphalt and SBS modified asphalt *(13)*. Table 1 shows energy consumption and GHG emission of some raw materials.

Table 1: Energy Consumption and GHG Emission of Some Raw Materials

Raw Materials	Virgin Asphalt	SBS Modified Asphalt	Aggregate
Energy consumption($MJ\cdot t^{-1}$)	2,830.76	5,412.22	31.99
GHG emission(kg $CO_2eq\cdot t^{-1}$)	189.12	323.04	2.38E-3

The energy consumed for asphalt rubber consists of two parts: rubber powder modifier and production. Liu *(14)* calculated the energy consumption and GHG emission of the rubber powder produced through crushing in low-temperature. University of California also analyzed the rubber powder production *(15)*.The energy consumption and GHG emission of rubber powder production is shown in Table 2, where extender oil is aromatic oil used to enhance the interaction between bitumen and CRM. Extender oil is absorbed and causes expansion of CRM particles, and helps CRM to disperse in the asphalt/rubber blend. The results show that there’s little difference between the foreign and domestic data. In this research, the domestic datum is adopted for analysis. As the rubber powder is reused, the tire production energy is not included.

Table 2: Energy Consumption and GHG Emission of Rubber Powder Production

Raw Materials		Energy Consumption ($MJ \cdot Kg^{-1}$)	Greenhouse Gas Emission ($Kg\ CO_2eq \cdot Kg^{-1}$)
China	Rubber powder	3.59	0.97
USA	Rubber powder	4.27	1.15
	Extender oil	54.1	3.61

Asphalt rubber is produced on the basis of virgin asphalt by adding rubber powder and modifier. According to the production process, asphalt rubber can be divided into field blended asphalt rubber (McDonald method, FBAR) and terminal blended asphalt rubber (TBAR). Suppose that the energy of heating asphalt during FBAR production is the same as that during the mixing. Therefore the energy consumption of field blended asphalt rubber includes that of rubber powder and virgin asphalt production. But for TBAR, besides the energy consumption of production of rubber powder and virgin asphalt, the energy consumed by colloid mill is also included. The survey results suggest that production of per ton TBAR consumes 3.5-5kw·h electricity and 6-8kg fuel oil, and the average value is taken for analysis. The energy consumption and GHG emission of different asphalt is shown in Table 3 and Figure 2.

Table 3: Energy Consumption and GHG Emission of Different Asphalt

Type	Rubber Powder Content (Wt %)	Energy Consumption ($MJ \cdot T^{-1}$)	GHG Emission ($Kg\ CO_2eq \cdot T^{-1}$)
Virgin asphalt	-	2830.76	189.12
SBS modified asphalt	-	5412.22	323.04
FBAR	18	3156.17	343.79
TBAR	20	3292.70	372.50

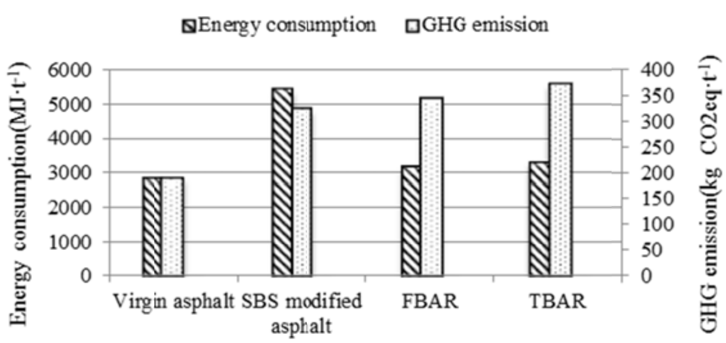

Figure 2: Energy consumption and GHG emission of different asphalt.

According to the results, energy consumption of asphalt rubber production is significantly lower than that of SBS modified asphalt. The main reason is that the tire powder is used as waste utilization, while the production of SBS modifier in SBS modified asphalt consumes much more energy. But the GHG emission of asphalt rubber is higher than SBS modified asphalt. The production of asphalt rubber consumes much more electricity which greenhouse gas emission coefficient is relatively higher.

TRANSPORTATION OF MATERIALS

Referring to CLCD, a 30t diesel truck was selected as the standard transportation mode. The energy consumption and GHG emission are shown in Table 4.

Table 4: Energy Consumption and GHG Emission of 30t Diesel Truck

Transportation Mode $(T{\cdot}Km)^{-1}$	Energy Consumption (MJ)	GHG Emission (kg)
30t diesel truck	0.804	0.075

LCA OF HOT MIX ASPHALT PAVEMENT

Mixture Production

The production of asphalt mixture mainly adopts batch asphalt mixing plant in China. In this research, several experienced asphalt pavement construction companies were investigated for the reliable and accurate energy data. Average energy consumption is taken as a representative value. Typical pavement asphalt mixtures were chosen for analysis, mainly including the following mixture types: bottom course of AC-25 or Sup-25 with virgin asphalt by asphalt-aggregate ratio of 4.4%; intermediate course of AC-20 or Sup-20 with SBS modified asphalt by asphalt-aggregate ratio of 4.8% and surface course of AK-13 or SMA-13 by asphalt-aggregate ratio of 5.2% or 6.0%.

<u>Energy Consumption of Loader</u>
Through investigation, the average diesel consumption of loader in mixing plant is 0.112 $kg{\cdot}t^{-1}$, that is 4.78 $MJ{\cdot}t^{-1}$, and the corresponding GHG emission is 0.355$kg{\cdot}t^{-1}$.

<u>Energy Consumption for Heating Asphalt</u>
The energy consumption for heating asphalt is varied with the asphalt types. The investigation result suggests that the temperature of heating SBS modified asphalt is higher, the fuel consumption for SBS-modified and virgin asphalt is 4.4$kg{\cdot}t^{-1}$ and 4$kg{\cdot}t^{-1}$, that is 187.67$MJ{\cdot}t^{-1}$ and170.61$MJ{\cdot}t^{-1}$, the corresponding GHG emission is 13.95$kg{\cdot}t^{-1}$ and 12.69$kg{\cdot}t^{-1}$.

<u>Electricity Consumption of Mixing Plant</u>
The energy mixing plant consumes covers electricity and fuel oil. The electricity consumption can be calculated by the power of machine and production efficiency, according to investigation results, 9.45 $MJ{\cdot}t^{-1}$ is taken as the representative value of common mixing plant, and the corresponding GHG emission is 2.58$kg{\cdot}t^{-1}$. SMA mixture production lasts longer than ordinary one, and the production efficiency is about 85% of the ordinary mixture, therefore the energy consumption is about 11.22$MJ{\cdot}t^{-1}$ with the GHG emission of 3.04 $kg{\cdot}t^{-1}$.

<u>Fuel Oil Consumption of Mixing Plant</u>
The heavy oil is usually used by mixing plant, and it can be converted to caloric referring to calorific value. The investigation results represent the level of production, the average fuel consumption of virgin asphalt mixture is 6.82$kg{\cdot}t^{-1}$, while the SBS modified asphalt mixture consumes 7.45$kg{\cdot}t^{-1}$ for higher heating temperature. The standard energy consumption is 285.19 $MJ{\cdot}t^{-1}$ and 311.53 $MJ{\cdot}t^{-1}$ according to the heavy oil conversion coefficient, and the corresponding GHG emission is 22.07 $kg{\cdot}t^{-1}$ and 24.11 $kg{\cdot}t^{-1}$.

Paving and Compaction

The speed of asphalt paver should be adapted to the production of mixing plant, thickness and width of pavement. Usually the paving speed of SMA pavement is lower than virgin asphalt pavement, and the typical construction speed of 2.5m·min^{-1} and 3 m·min^{-1} is selected for SMA and ordinary pavement. The energy consumption of paving and compaction can be calculated according to the power of machines and production efficiency. And the average result is taken as the representative value.

Data Summarization

According to the analysis and calculation results, the energy consumption and greenhouse gas emission of typical HMA pavement are shown in Table 5.

Table 5: Energy Consumption and GHG Emission of Typical Asphalt Pavement

Construction Process		Energy And Emission	Typical Type Of Pavement			
			Surface Course	Intermediate Course	Bottom Course	SMA Pavement
Raw materials	Asphalt	Energy consumption(MJ·t^{-1})	267.52	247.89	119.30	306.35
		GHG(kg·t^{-1})	15.97	14.80	7.97	18.29
	Aggregate	Energy consumption(MJ·t^{-1})	30.25	30.36	30.48	30.02
		GHG (kg·t^{-1})	2.31	2.31	2.32	2.29
Transportation of raw materials (50km)		Energy consumption(MJ·t^{-1})	40.20			
		GHG (kg·t^{-1})	3.74			
Mixture mixing		Energy consumption(MJ·t^{-1})	334.99	334.99	307.80	336.67
		GHG (kg·t^{-1})	27.81	27.81	25.70	28.26
Transportation of Mixture (20km)		Energy consumption(MJ·t^{-1})	16.08			
		GHG (kg·t^{-1})	1.50			
Pavement construction	Paving	Energy consumption(MJ·t^{-1})	13.22	8.81	7.34	15.86
		GHG (kg·t^{-1})	0.98	0.66	0.55	1.18
	Compaction	Energy consumption(MJ·t^{-1})	13.23	12.48	10.39	18.60
		GHG (kg·t^{-1})	0.98	0.93	0.77	1.38
Total		Energy consumption(MJ·t^{-1})	715.49	690.81	531.59	763.78
		GHG (kg·t^{-1})	53.29	51.75	42.55	56.64

The results show that, the energy consumption varies from different asphalt pavement types. The SMA pavement consumes the most energy of about 760 MJ·t^{-1}, while the bottom course consumes the lowest of 530 MJ·t^{-1}. The difference mainly caused by the high consumption of SBS modified asphalt and lower production efficiency. Among each construction process, the raw materials production consumes about 40% of the total. The mixing process uses the energy of about 40%-50% while paving and compaction processes consume only 4% of the total.

LCA OF ASPHALT RUBBER PAVEMENT

The main difference between asphalt rubber mixture and SBS modified asphalt mixture is the different type of modified asphalt. The mixing temperature of FBAR mixture is about 15-20℃ higher than that of SBS modified asphalt mixture, while the TBAR is 5-10℃ higher. The energy consumption of mixing increases about 10% and 5% respectively according to relevant research conclusions *(8)*. Based on the above data, the production energy consumption of FBAR, dry method with Trans-Polyoctenamer (TOR) and TBAR can be calculated with a comparison with SBS modified asphalt SMA mixture. The calculation result is shown in Table 6, Figure 3 and Figure 4. The output of rubber powder from waste tires is 70%.

Table 6: Energy Consumption and GHG Emission of Different Type of AR

Mixture			AC13	SMA13	SMA13	SMA13
Asphalt type			FBAR	TBAR	TOR	SBS modified asphalt
Asphalt content (%)			7.41	5.75	5.00	5.75
Raw materials	Asphalt	Energy consumption(MJ·t^{-1})	233.87	189.33	206.67	311.20
		GHG(kg·t^{-1})	25.47	21.42	23.66	18.57
		Recycling utilization (kg·t^{-1})	19.05	16.43	15.43	—
	Aggregate	Energy consumption(MJ·t^{-1})	29.46	29.99	29.89	29.99
		GHG (kg·t^{-1})	2.25	2.29	2.28	2.29
Transportation of raw materials (50km)		Energy consumption(MJ·t^{-1})	40.20			
		GHG (kg·t^{-1})	3.74			
Mixture mixing		Energy consumption(MJ·t^{-1})	370.34	353.50	336.67	336.67
		GHG (kg·t^{-1})	31.09	29.67	28.26	28.26
Transportation of Mixture (20km)		Energy consumption(MJ·t^{-1})	16.08			
		GHG (kg·t^{-1})	1.50			
Pavement construction	Paving	Energy consumption(MJ·t^{-1})	15.86			
		GHG (kg·t^{-1})	1.18			
	Compaction	Energy consumption(MJ·t^{-1})	18.60			
		GHG (kg·t^{-1})	1.38			
Total		Energy consumption(MJ·t^{-1})	724.41	663.56	663.97	768.6
		GHG (kg·t^{-1})	66.61	61.18	62	56.92
		Recycling utilization (kg)	19.05	16.43	15.43	-

Note: the virgin asphalt content of trans-polyoctenamer asphalt mixture is 5.0%, the rubber powder content is 1.08%, and the extender oil content is 4.5% of the rubber powder.

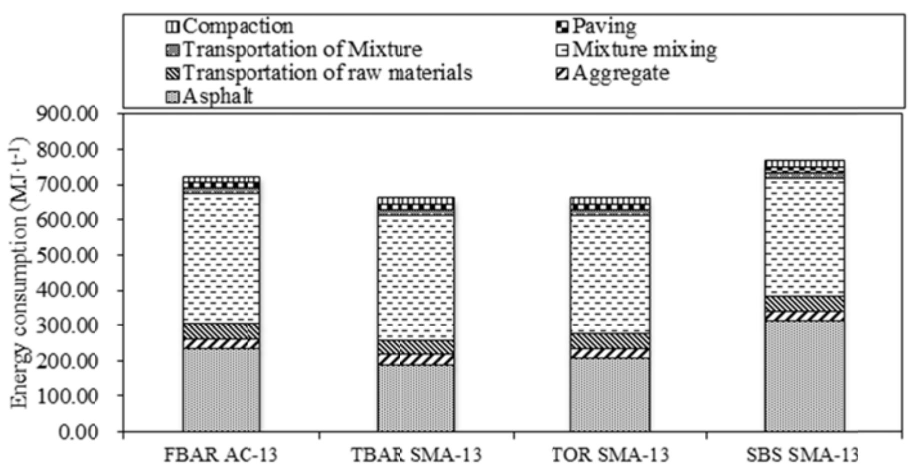

Figure 3: Energy consumption of asphalt rubber mixture production.

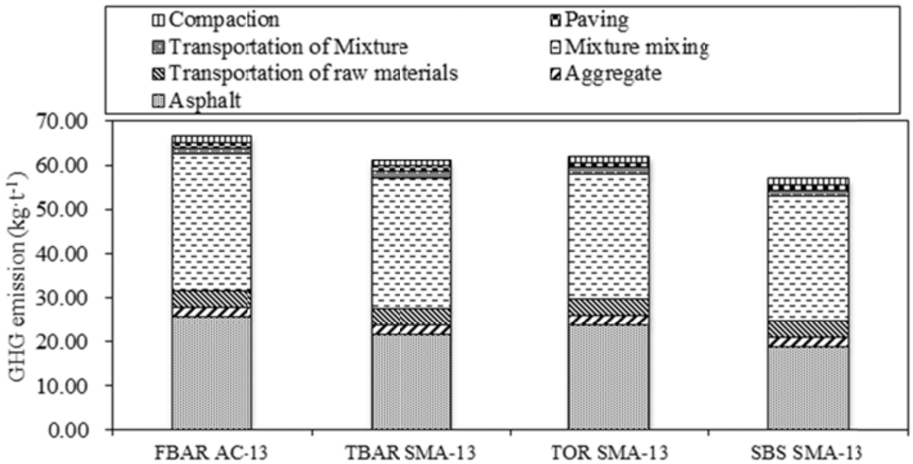

Figure 4: GHG emission of asphalt rubber mixture production.

The results show that:

1. Although the mixing energy consumption of AR mixture is higher than SBS modified asphalt mixture, the total energy consumption of FBAR mixture is 5.75% lower than SBS modified asphalt mixture, and the TBAR and TOR mixture are 13.66% and 13.61% lower. Therefore AR has obvious advantages in energy conservation over the life cycle. Due to higher asphalt content in FBAR mixture and higher mixing temperature, the total energy consumption is higher than TBAR mixture. The TOR asphalt rubber mixture doesn't need additional energy for asphalt rubber production, but needs adding some extender oil, so the total energy consumption is nearly the same as TBAR mixture.
2. As the GHG emission of asphalt rubber is obviously higher than SBS modified asphalt mixture, and the mixing process consumes more energy, therefore the GHG emission of FBAR, TBAR and TOR mixture is 17.03%, 7.48% and 8.92% higher than SBS modified asphalt mixture. The asphalt rubber doesn't have obvious benefits in emission reduction.
3. Asphalt rubber mixture can reuse waste tires, and the mass of rubber powder utilized of per ton mixture is 19.05kg, 16.43kg and 15.43kg in FBAR, TBAR and TOR asphalt rubber mixture respectively. Assuming one waste tire can produce 8kg rubber powder, per ton mixture can reuse 2-2.5 waste tires.

CONCLUSIONS

This research investigated the energy consumption and GHG emission and established the LCI database of HMA and AR pavement in China. From the preliminary findings in this research, the following conclusions were drawn:

1. The energy consumption varies from different asphalt pavement types. The SMA pavement consumes the most energy of about 760 $MJ \cdot t^{-1}$, while the bottom course consumes the lowest of 530 $MJ \cdot t^{-1}$. Among the construction phase, the mixing process accounts for the largest portion of about 40%-50% in energy, while paving and compaction processes consume only 4% of the total.
2. The energy consumption of FBAR mixture is 5.75% lower than SBS modified asphalt mixture, and the TBAR and TOR mixture are 13.66% and 13.61% lower. Therefore AR has obvious advantages in energy conservation over the life cycle.

3. Asphalt rubber mixture can reuse waste tires, and the mass of rubber powder utilized of per ton mixture is 19.05kg, 16.43kg and 15.43kg in FBAR, TBAR and TOR asphalt rubber mixture respectively, and per ton mixture can reuse 2-2.5 waste tires.

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Part 3: Studies focused on use phase