Carbon Footprint of Automobiles
IPRO 322

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&

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VILNIAUS GEDIMINO
SAPERE
AUDE

Purpose

The purpose of this IPRO is to develop and present a “user friendly” way of identifying vehicles with respect to the emission of greenhouse gases throughout their life cycle.

Objectives

- ‘Accurate’ carbon footprint
- Derive a standard for calculating an accurate footprint
- Design consumer-friendly and meaningful way of presenting footprint information
- Steer manufacturing processes
- Research global standards (manufacturing, recycling and use)

Global Climate Change

- A global problem
- 75% of GHGs is CO_2
- CO_2 primarily emitted by burning of fossil fuels
- Automobiles 2^{nd} highest source of CO_2 in U.S.
  - Over 250 million registered vehicles in U.S.

Carbon Footprint

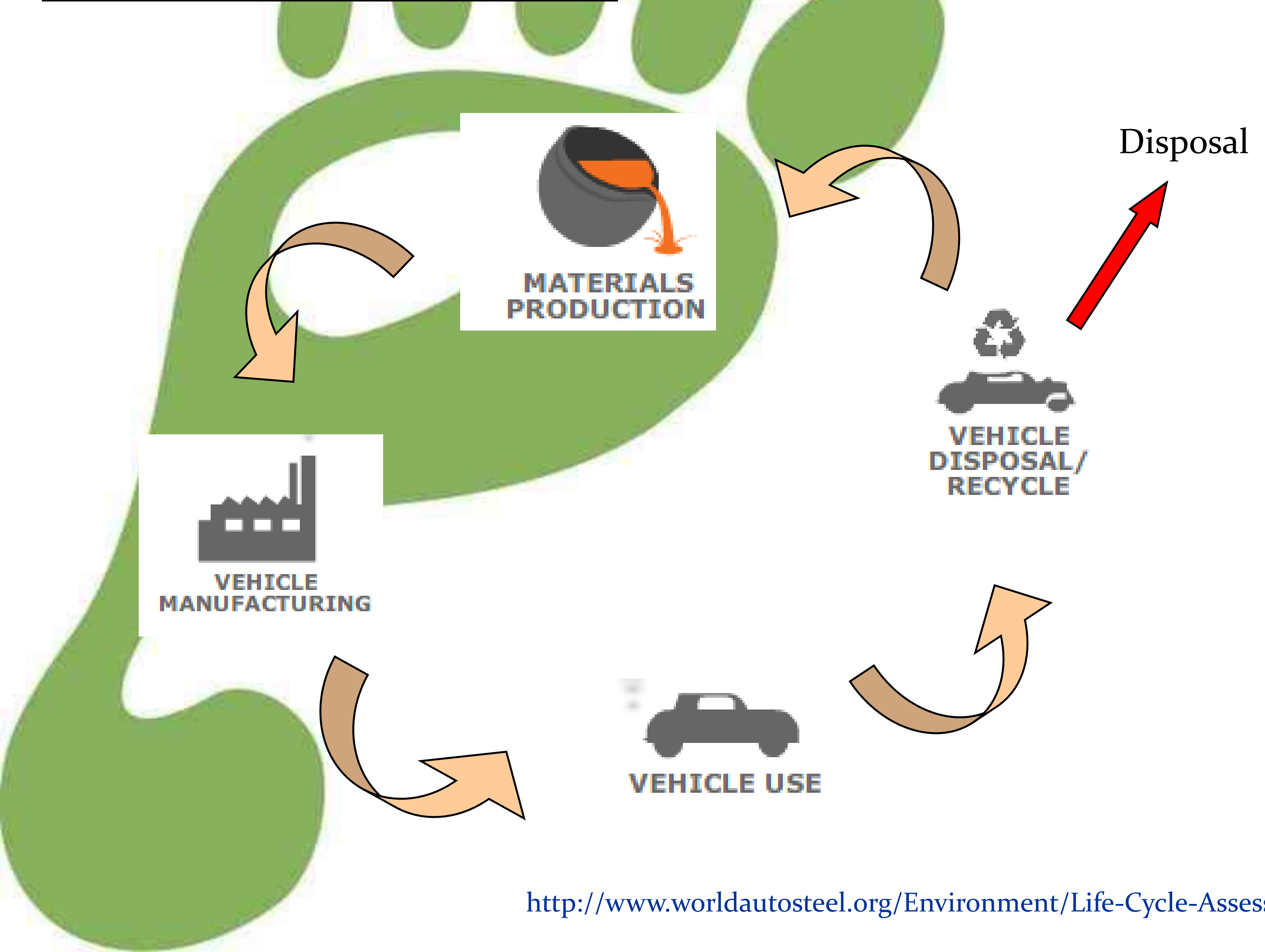
- GHG produced to directly and indirectly support human activities (tons CO_2)
- Personal carbon footprint
- U.S. is improving availability of information
- EU mandates manufacturers provide information

- How are these values derived?
- What do these numbers mean?

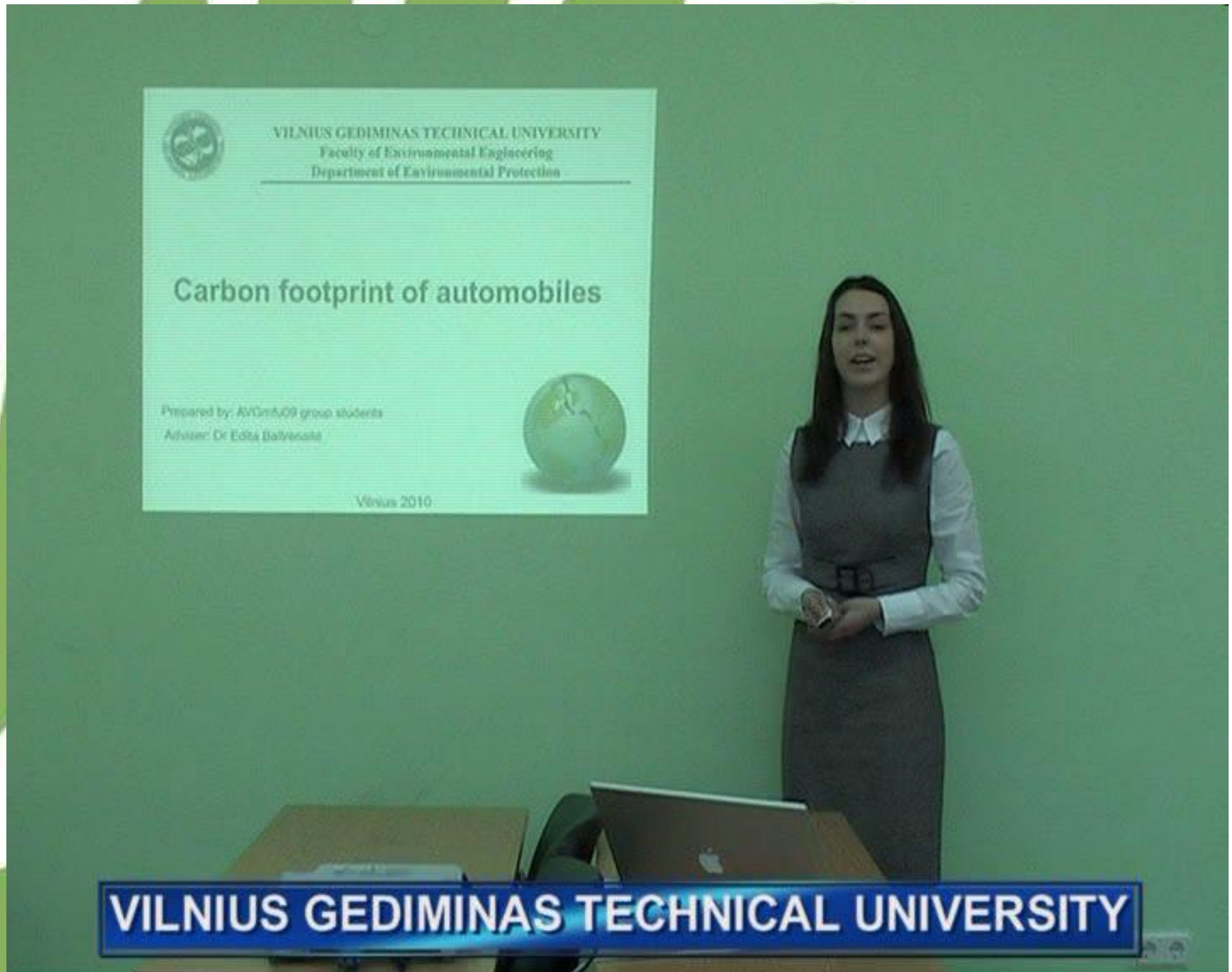
Carbon Footprint Assessment

- Life-Cycle
  - Production (Materials, Manufacturing, Assembly)
  - Disposal /Recycling
- Fuel-Cycle
  - Extraction and tail pipe (MPG)
- Final Vehicle Choices
  - Audi A3, Mazda 5, Nissan Leaf, Hyundai Sonata, BMW X5d, Chevrolet Impala

LIFE CYCLE assessment



http://www.worldautosteel.org/Environment/Life-Cycle-Assessment.aspx


VILNIUS GEDIMINAS TECHNICAL UNIVERSITY
Faculty of Environmental Engineering
Department of Environmental Protection
Carbon footprint of automobiles
Vilnius 2010
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Chevrolet Impala – The Model Car

- To find values for Manufacturing, Fuel Cycle, and Recycling/Disposal, there were many things to consider
- We will demonstrate how we were able to find these values for one model vehicle

GREET MODEL

- Materials Breakdown – Vehicle Material Composition by Weight.

	ICEV: Conventional Material	ICEV: Light-weight Material	HEV: Conventional Material	HEV: Light-weight Material	FCV: Conventional Material	FCV: Light-weight Material
Steel	61.7%	30.5%	65.2%	30.9%	56.4%	21.6%
Stainless Steel	0.0%	1.1%	0.0%	0.7%	0.0%	0.0%
Cast Iron	11.1%	4.2%	6.0%	3.7%	1.8%	2.6%
Wrought Aluminum	2.2%	6.9%	1.8%	6.3%	5.9%	9.6%
Cast Aluminum	4.7%	14.7%	5.1%	14.1%	3.2%	11.4%
Copper/Brass	1.9%	3.2%	4.3%	5.4%	4.8%	5.5%
Magnesium	0.02%	0.4%	0.02%	0.4%	0.02%	0.3%
Glass	2.9%	3.0%	2.9%	3.0%	2.6%	2.8%
Average Plastic	11.2%	14.0%	10.6%	12.6%	10.2%	11.7%
Rubber	2.4%	2.6%	1.9%	2.0%	1.8%	1.9%
Carbon Fiber-Reinforced Plastic	0.0%	15.1%	0.0%	16.0%	10.0%	26.4%
Glass Fiber-Reinforced Plastic	0.0%	2.3%	0.0%	2.4%	0.0%	2.4%
Nickel	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
PFSA	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%
Carbon Paper	0.0%	0.0%	0.0%	0.0%	0.4%	0.4%
PTFE	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%
Carbon & PFSA Suspension	0.0%	0.0%	0.0%	0.0%	0.05%	0.05%
Platinum	0.0005%	0.0009%	0.0003%	0.0004%	0.007%	0.007%
Others	1.9%	2.2%	2.2%	2.5%	2.2%	2.6%

Production

- Reduced to 3 main components - ~88%
- Steel (70%) – includes iron
- Plastics (15%) – various plastics
- Glass (3%)

Production

- Calculated from national averages of ~50% Coal and 20% Natural Gas
- 0.6 Kg CO_2/kWh
- kg CO_2/kg material – standard
- Many conversion needed

Impala – Production (Steel)

- From – $Car(lbs)\times(70\%)\times\left(\frac{1lb}{2.204kg}\right)\times\left(\frac{2kgCO_2}{kg\_steel}\right)$
- Where – $\left(\frac{3.3kWh}{kg\_steel}\right)=\left(\frac{2kgCO_2}{kg\_steel}\right)$
- **Total CO_2 from Steel = 2,258 kg CO_2**

Impala – Production (Plastic)

- From – $Car(lbs)\times(15\%)\times\left(\frac{1lb}{2.204kg}\right)\times\left(\frac{7.2kgCO_2}{kg\_plastic}\right)$
- Where – $\left(\frac{12kWh}{kg\_plastic}\right)=\left(\frac{7.2kgCO_2}{kg\_plastic}\right)$
- **Total CO_2 from Plastic = 1,742 kg CO_2**

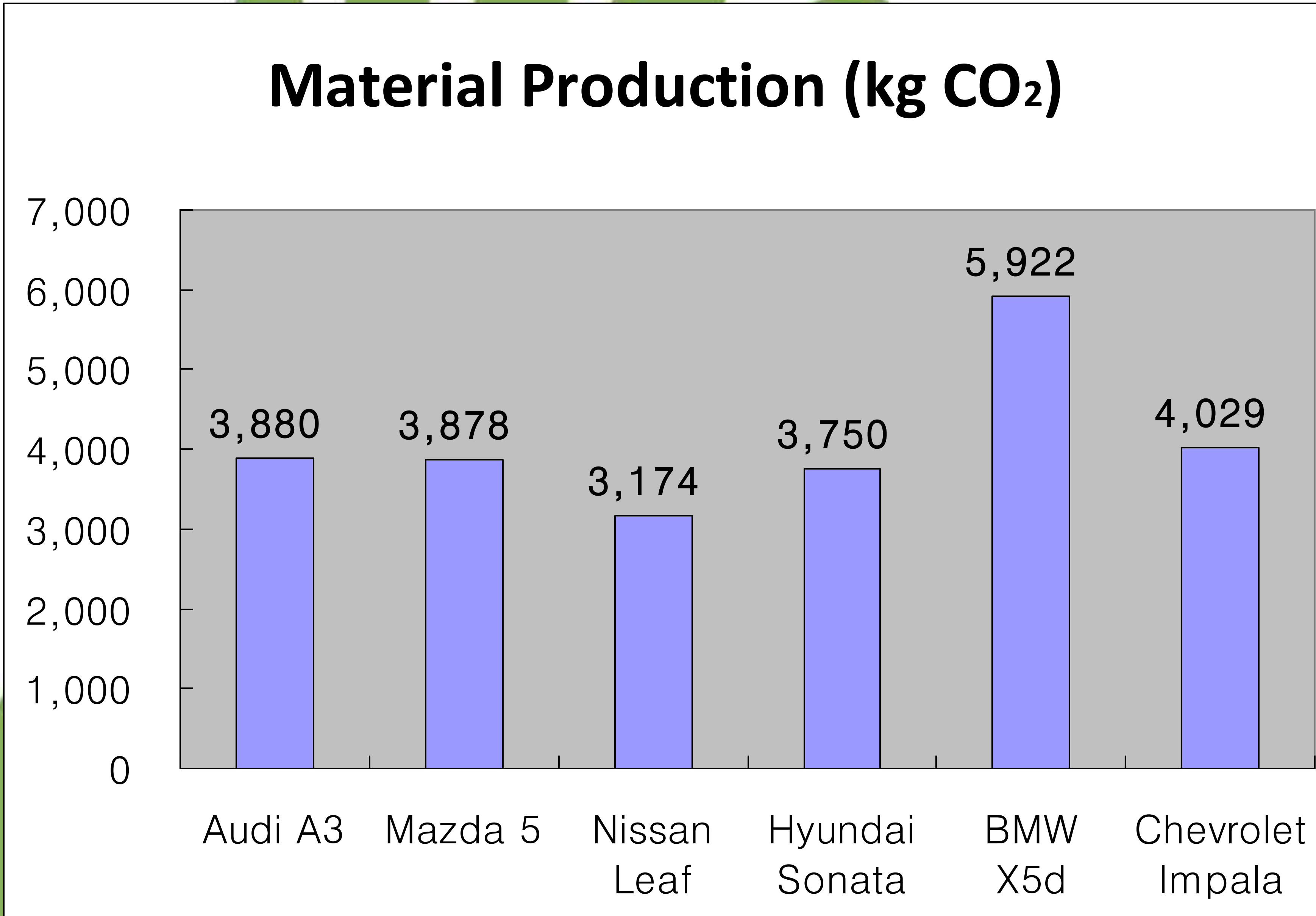
Impala – Production (Glass)

- From – $$Car(lbs)\times(3\%)\times\left(\frac{1lb}{2.204kg}\right)\times\left(\frac{0.6kgCO_2}{kg\_glass}\right)$$
- Where – $$\left(\frac{0.985kWh}{kg\_glass}\right)=\left(\frac{0.6kgCO_2}{kg\_glass}\right)$$
- **Total CO_2 from Glass = 29 kg CO_2**

Impala – Production (Total)

- Summary
  - Steel Total = 2,258 kg CO_2
  - Plastic total = 1,742 kg CO_2
  - Glass Total = 29 kg CO_2

- TOTAL CO_2 emitted = 4,029 kg


Material Production (kg CO₂)
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
3,880
3,878
3,174
3,750
5,922
4,029
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala

Impala – Production (Extraction - Steel)

- From –

$$\text{car weight(lbs)} \times 70\% \times \left(\frac{1\text{lb}}{2.204\text{kg}}\right) \times \left(\frac{13\text{kg } CO_2}{\text{kg\_steel}}\right)$$

- Where –
  - 13kg CO_2 per 1kg of steel (from greenmatrix.org)

- **Total = 14,678 kg CO_2 emission produced for virgin steel used**

- Plastic – 34kg CO_2 / kg_plastic

- Tempered Glass – 10kg CO_2 / kg_glass

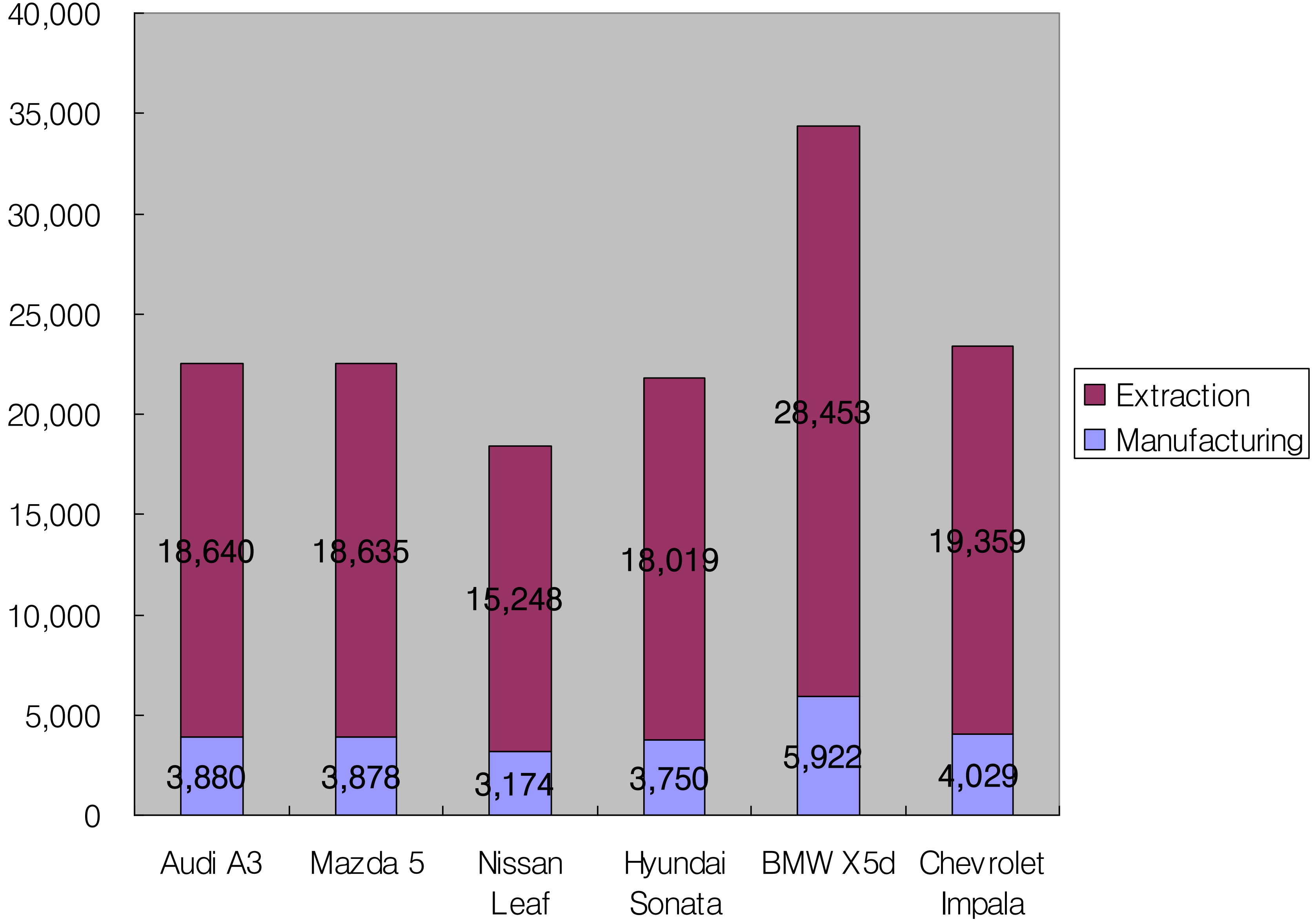
Impala – Production (Extraction)

- From –
  - Extraction = (Manufacturing + Extraction) – (Manufacturing)

- Where –
  - Total Manufacturing + Extraction CO_2 emission
    - 23,388 kg CO_2 emission
  - Total Manufacturing CO_2 emission
    - 4,029 kg CO_2 emission

- **Total Extraction only = 19,359 kg CO_2 emission**

Manufacturing + Extraction (kg CO_2)



Assembly

- UNESCO (United Nations)
  - 20,000MJ per car
    - where : 1kWh/3,600J & 0.6kg CO_2/kWh
  - **Total : 3,333 kg CO_2 emission / car**

- GREET (United States)
  - 3.9 million Btu per car
    - where : 1kWh/3413Btu & 0.6kg CO_2/kWh
  - **Total : 685.6 kg CO_2 emission /car**

Impala – Fuel Cycle (Tailpipe)

~Gasoline MPG: 22

$$\left(\frac{150{,}000\ \text{miles}}{\text{life}}\right) \times \left(\frac{1\text{gal\_gasoline}}{\text{mpg(mile)}}\right) \times \left(\frac{8.834\ \text{kg}\ CO_2}{1\text{gal\_gasoline}}\right)$$

~60,232 kg CO_2

~Where Gas = 8.834 kg CO_2/gal

~Where Diesel = 10.493 kg CO_2/gal

Impala – Fuel Cycle (EPA)

~ EPA Value = 8.3 tons CO_2/Year

$$\left(\frac{Car(tonsCO_2)}{1Year}\right)\times\left(\frac{907.185(kg)}{1ton}\right)\times\left(\frac{1Year}{15,000(Miles)}\right)$$

~ .50 Kg/Mile

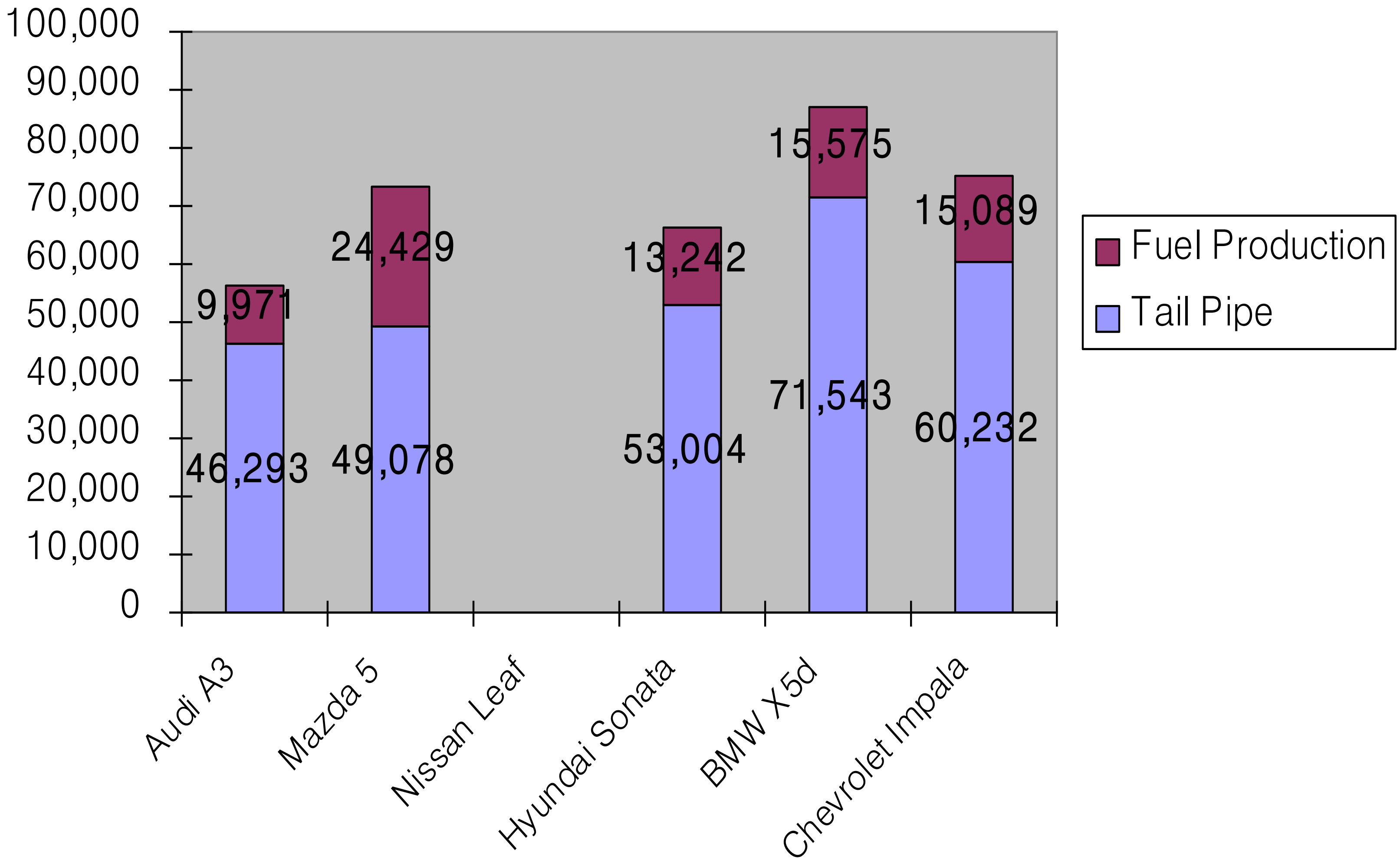
$$\left(\frac{Car(kgCO_2)}{1Mile}\right)\times\left(\frac{150,000(Miles)}{Lifetime}\right)$$

~75,321 kg CO_2

Impala – Fuel Cycle

- Fuel-Cycle
  - Tail Pipe: 60,232 kg
  - Fuel Extraction: 15,089 kg
- Total = 75,321 kg

Fuel Cycle (kg of CO_2 emitted)



Vehicle Recycling

- Values are difficult to find for Recycling and Disposal
- Focused on Recycling
- Should Recycling be a CO_2 benefit or a CO_2 cost
- Recycling as a benefit
- Greenmatrix.org – only available information

Recycled Steel

- From Greenmatrix.org –
  - Virgin Steel – 10 kg CO_2/kg Steel
  - Recycled Steel – 4 kg CO_2/kg Steel
- Values include extraction and production
- Cars can be made of up to 25% recycled steel

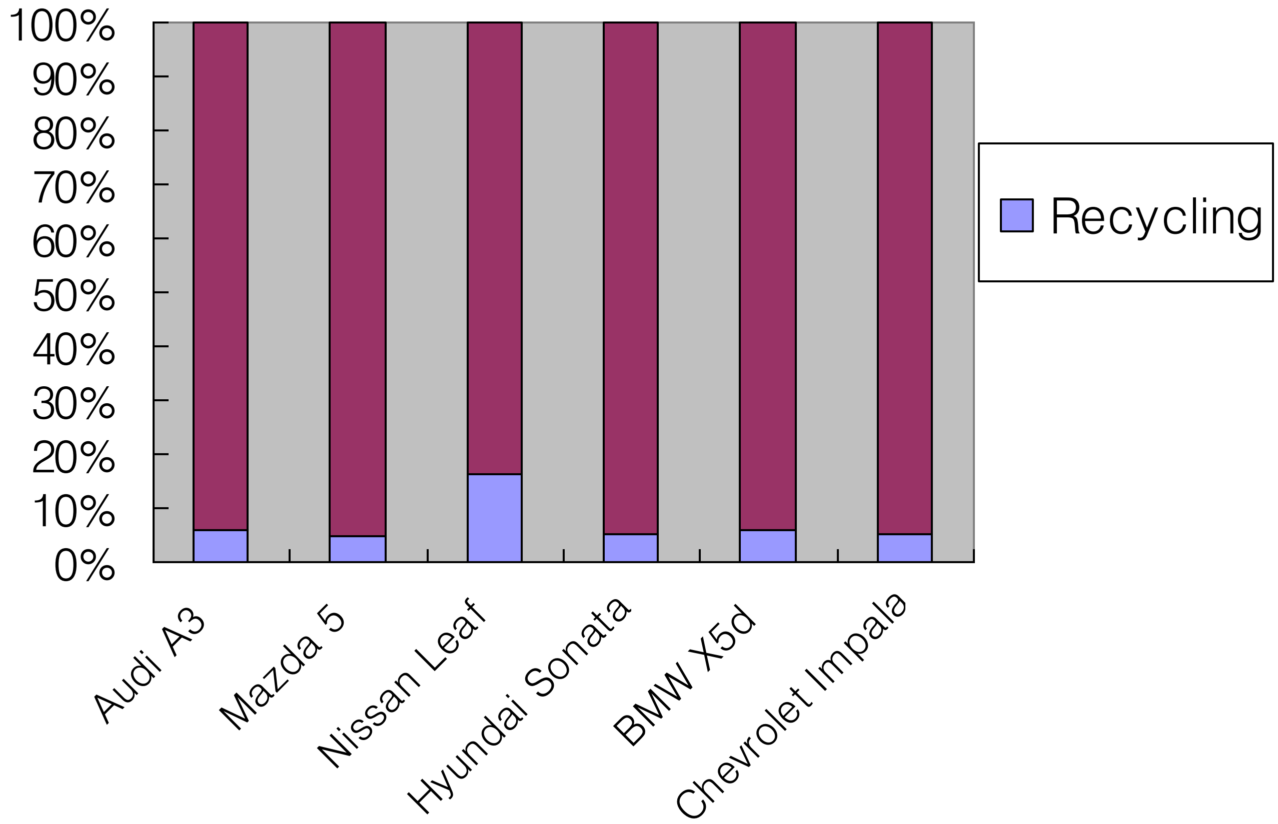
Impala – Production (Recycling benefit)

- 75% Virgin Steel and 25% Recycled-

$$\left[Car(lbs)\times(70\%)\times\left(\frac{1lb}{2.204kg}\right)\right]\times\left[0.75\left(\frac{10kgCO_2}{kg\_Virgin}\right)+0.25\left(\frac{4kgCO_2}{kg\_\mathrm{Re}cycled}\right)\right]$$

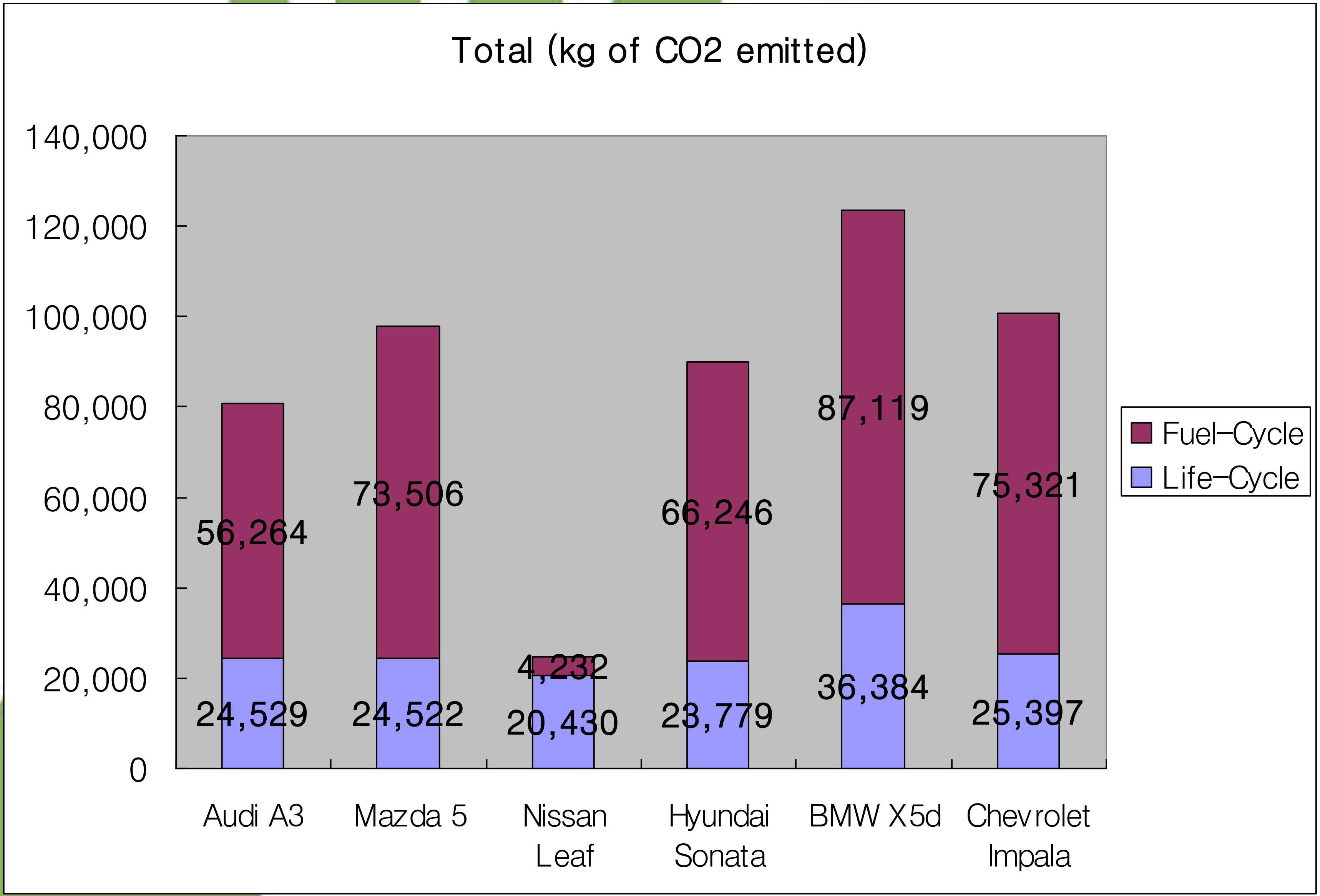
- **Total CO_2 = 9,597 kg CO_2**
- **CO_2 emissions benefit = 5,081 kg CO_2**

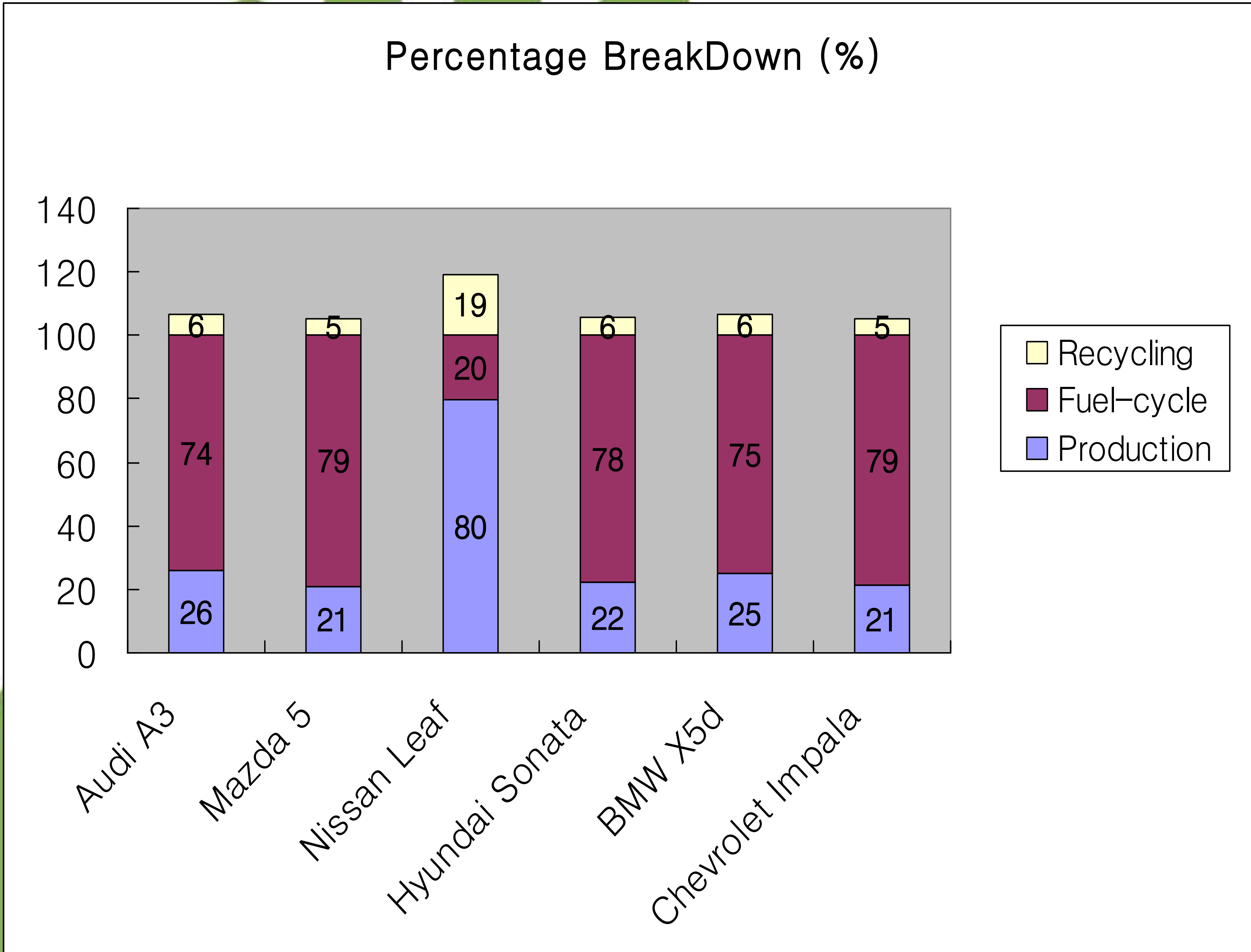
Recycling Benefit



Impala – Life-Cycle (Total)

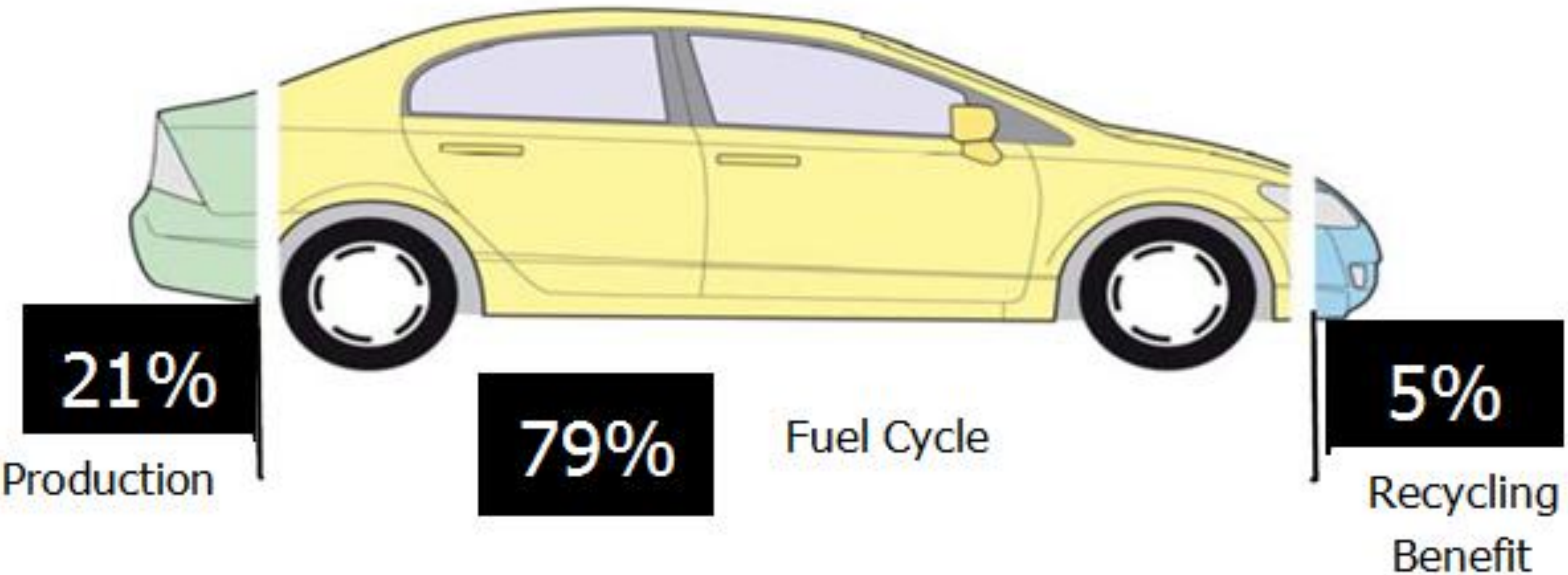
- Life-Cycle :
  - Material Production: 4,030 kg
  - Material Extraction: 19,360 kg
  - Assembly: 3,333 kg or 685.6 kg
  - Recycling: -5,081 kg (Benefit)
- Total = 18,995 - 21,642 kg CO_2


Total (kg of CO2 emitted)
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
56,264
24,529
73,506
24,522
4,232
20,430
66,246
23,779
87,119
36,384
75,321
25,397
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala
Fuel-Cycle
Life-Cycle



Percentage BreakDown (%)
140
120
100
80
60
40
20
0
6
74
26
5
79
21
19
20
80
6
78
22
6
75
25
5
79
21
Recycling
Fuel-cycle
Production
Audi A3
Mazda 5
Nissan Leaf
Hyundai Sonata
BMW X5d
Chevrolet Impala

Impala – Car Model



Ethical Issues

- Composed of parties that reside both in the United States and Lithuania.
- Meetings, communication, and collaboration difficult
- The information on vehicles was not as readily available in the U.S. as it was in the European Union.
- Credit our counterparts and well as keep them involved as much as possible
- Falsifying data/estimating values

Conclusions

- Discrepancies exist between calculated value depending on considerations
- U.S. manufacturers do not provide any information

- Not globally mandated
- No standards exist
- Based on too many ‘flexible’ considerations
- Entire Life-cycle costs must be considered
- Environmental impact must be considered

Conclusions

- An accurate life-cycle calculation is important
- Significant differences were found
- Too many considerations; many ignored
  - Too many generalizations of materials
  - Extraction costs
  - Assembly
  - Recycling
- Standards must be created

Recommendations

- Research other models
- Establish more consistent communication with Lithuanian counterparts.
- Work directly with GREET to develop existing model.

Future

- Propose standards for footprints
- Design environmental impact ratings system
- Calculate actual footprint for one material
- Study one manufacturing plant
- Develop Sticker concept
- Study recycling values for an old car

Thank you