Possibility of Ethanol Usage as Diesel Substitute in Thai Transportation Sector

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Team Members

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5	Prof. Dr. Sumrueng Jugjai		KMUTT
6	**Dr. Nuwong Chollacoop**	**Project leader**	**MTEC**
7	Dr. Yossapong Laoonual	Co-Researchers	KMUTT
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10	Mr. Jakapong Pongthanaisawan	Research assistants	JGSEE/KMUTT
11	Mr. Peerawat Saisirirat		KMUTT

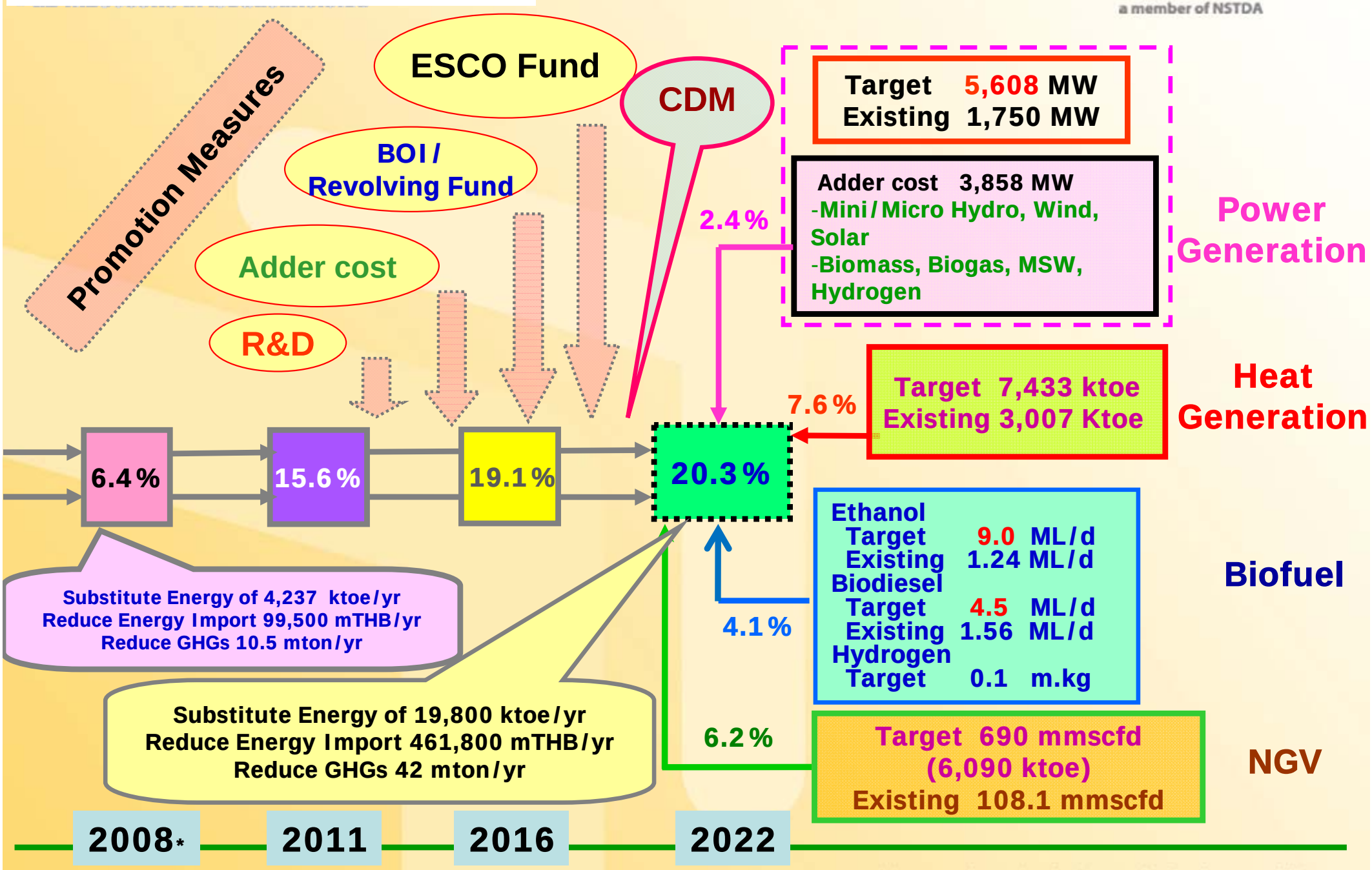
Outline

- Brief introduction of the project
  - Rationale, Objective, Methodology
- Energy demand model set up*
  - NV, FE, VKT
  - Validation with historical data & correction factor
- Scenario analysis
  - Business as usual (BAU) for baseline
  - Broadly divided into
    - ✓ Introduction of already commercialized ED95 bus in bus sector
    - ✓ Introduction of nearly commercialized ED95 vehicle in other sectors
  - Aim to benchmark 9 MLPD target in 2022
  - Evaluate effects on diesel fuel substitution and CO_2 emission reduction
- Conclusions & recommendation

*Details on poster outside

กรมพัฒนาพลังงานทดแทน
และอนุรักษ์พลังงาน
กระทรวงพลังงาน

Development Strategy on Alternative Energy for 2008 - 2022



Projected with 2008 average crude oil price of $94.45/barrel

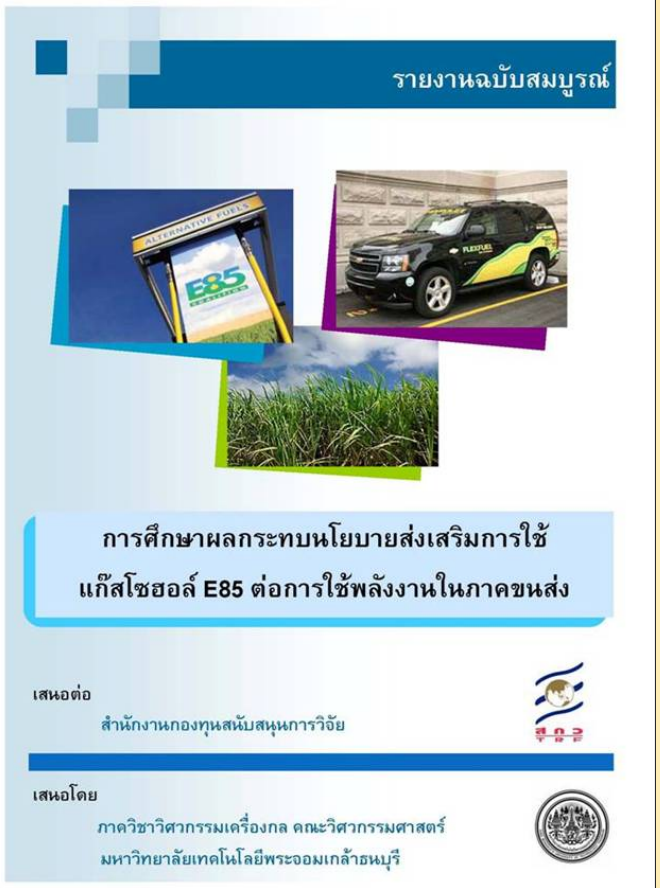
Remarks: * as of Jan 2009

Project Objective

- Aims to assess feasibility of using ethanol in transportation sector (especially as diesel substitute)
  - Construct a database model for energy consumption in transportation
  - Analyze above model for various scenarios to reflect different levels of diesel substitution by ethanol
  - Assess technical-economical feasibility of using ethanol as diesel substitute in transportation sector

Methodology

- Use LEAP* to construct energy demand model for transportation sector
- Run scenarios analysis on ED95 technology introduction



*Stockholm Environmental Institute, http://www.energycommunity.org/

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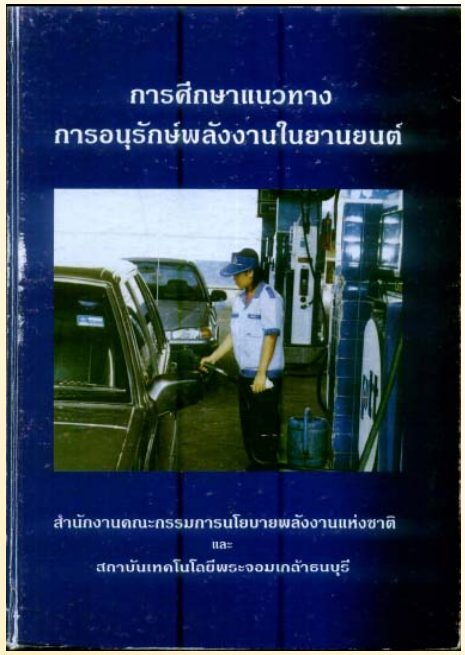
Basic of energy demand calculation

$$ED. = NV. \times VKT. \times FE.$$

(energy demand) = *(number of vehicle)* × *(vehicle kilometer of travel)* × *(fuel economy)*

Number of vehicles by types from DLT statistics

EPPO (2008)



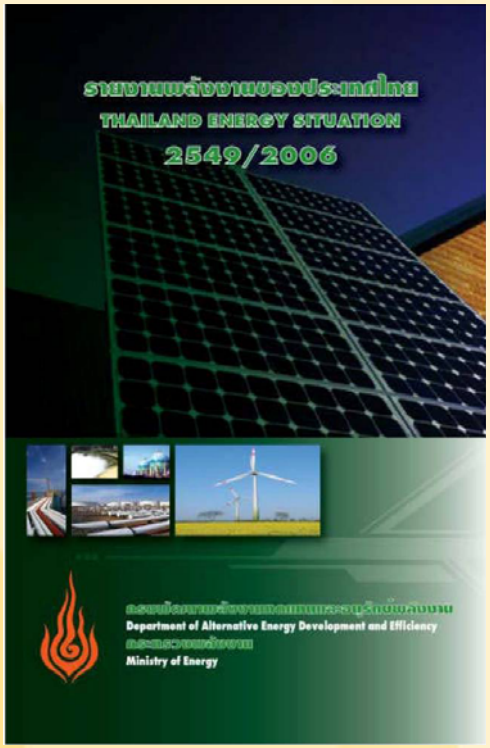
NEPO&KMUTT (1997)

DLT = Department of Land Transport

http://apps.dlt.go.th/statistics_web/statistics.html

Validation with historic records

Reports from
Department of Alternative
Energy Development and Efficiency (DEDE)



Thailand energy situation
2006, 2007, 2008

Thailand energy statistics
2009 (Preliminary report)

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Business As Usual (BAU)

Model assumption (2010 to 2020)

New SI car => E20 within 10 years[1]

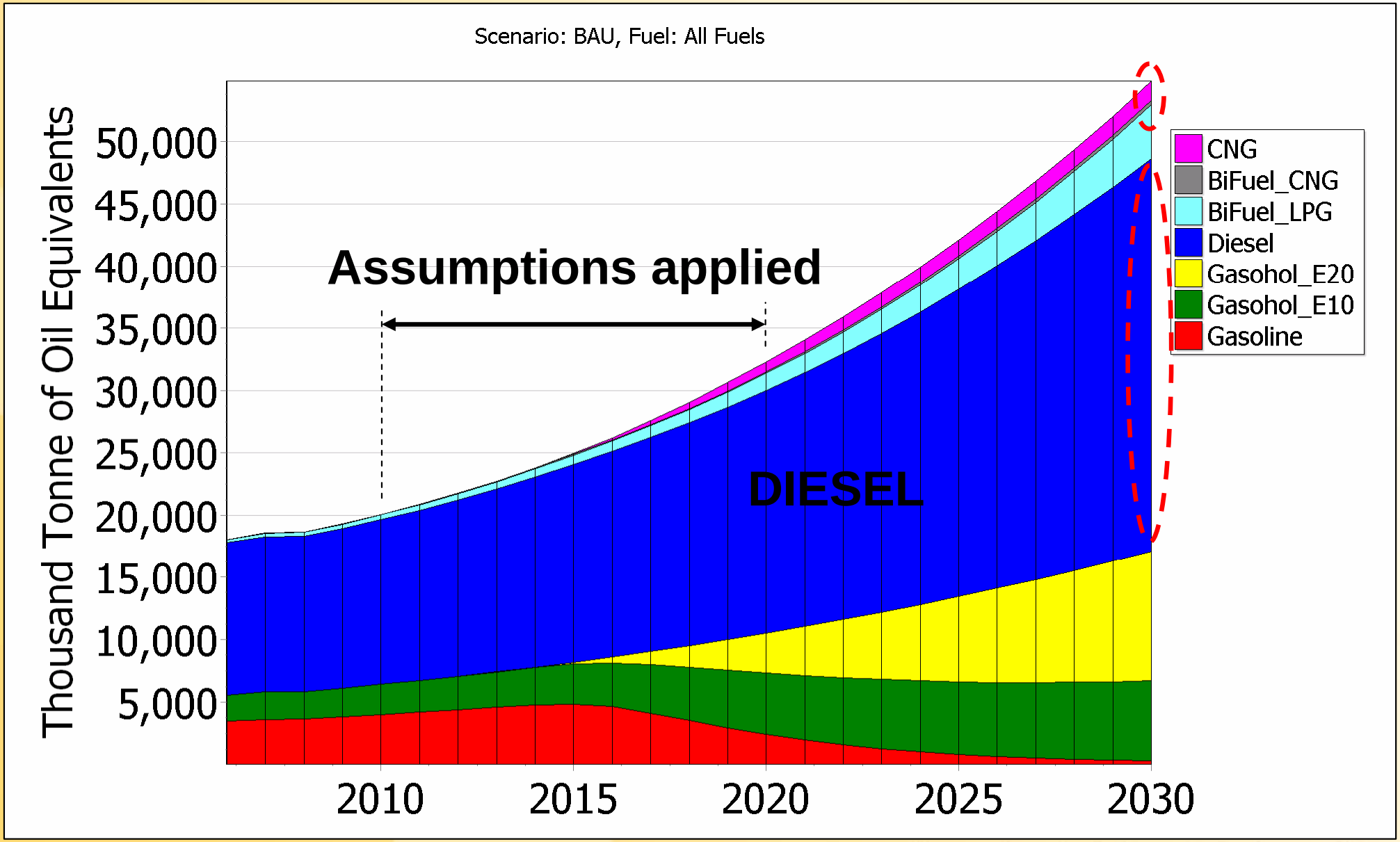
New SI motor-cycle => E10 within 10 years[1]

New fixed route bus => NGV bus within 10 years[2]

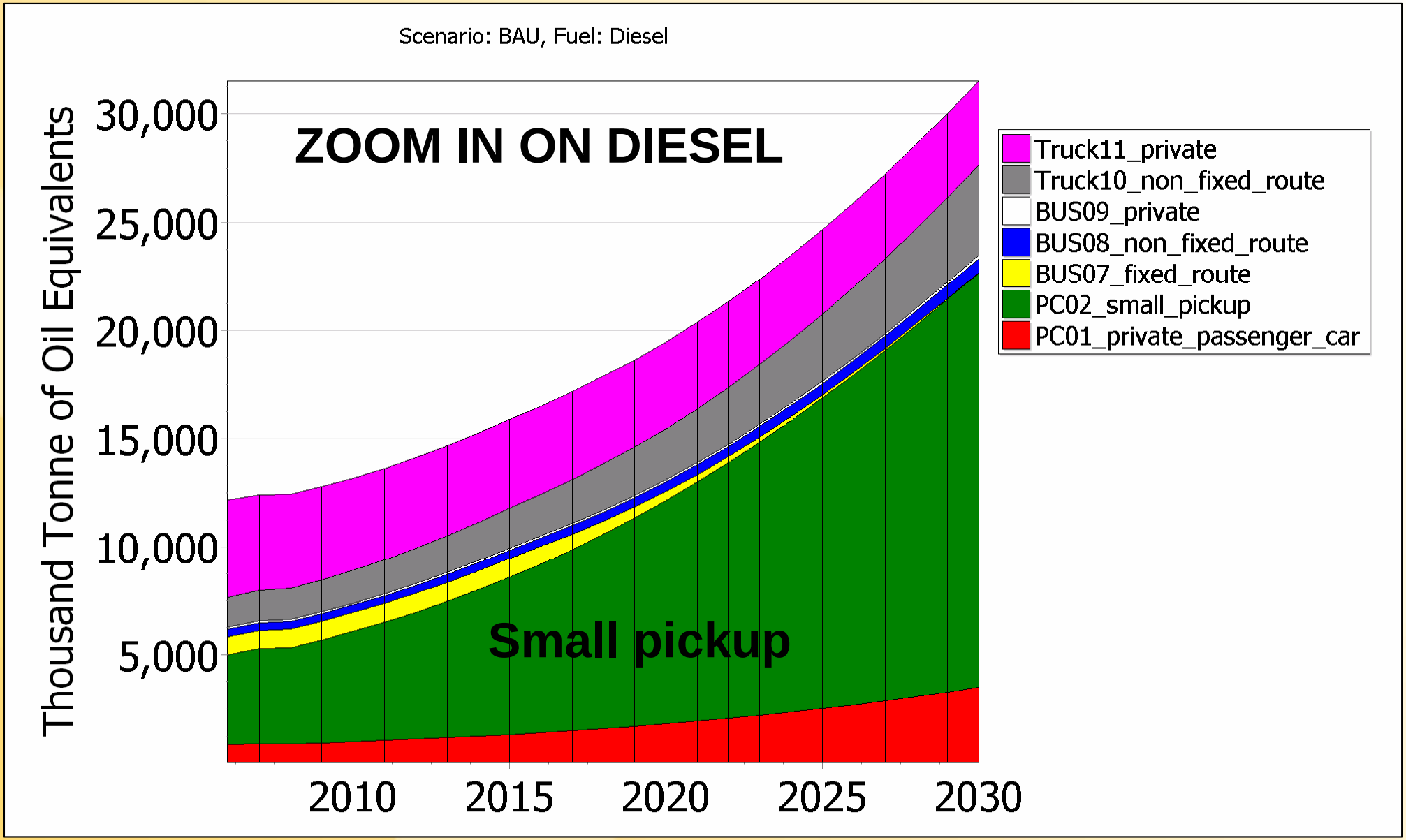
[1]E-policy report (E85 promotion plan)

[2]Cabinet resolution on 27 May 2008

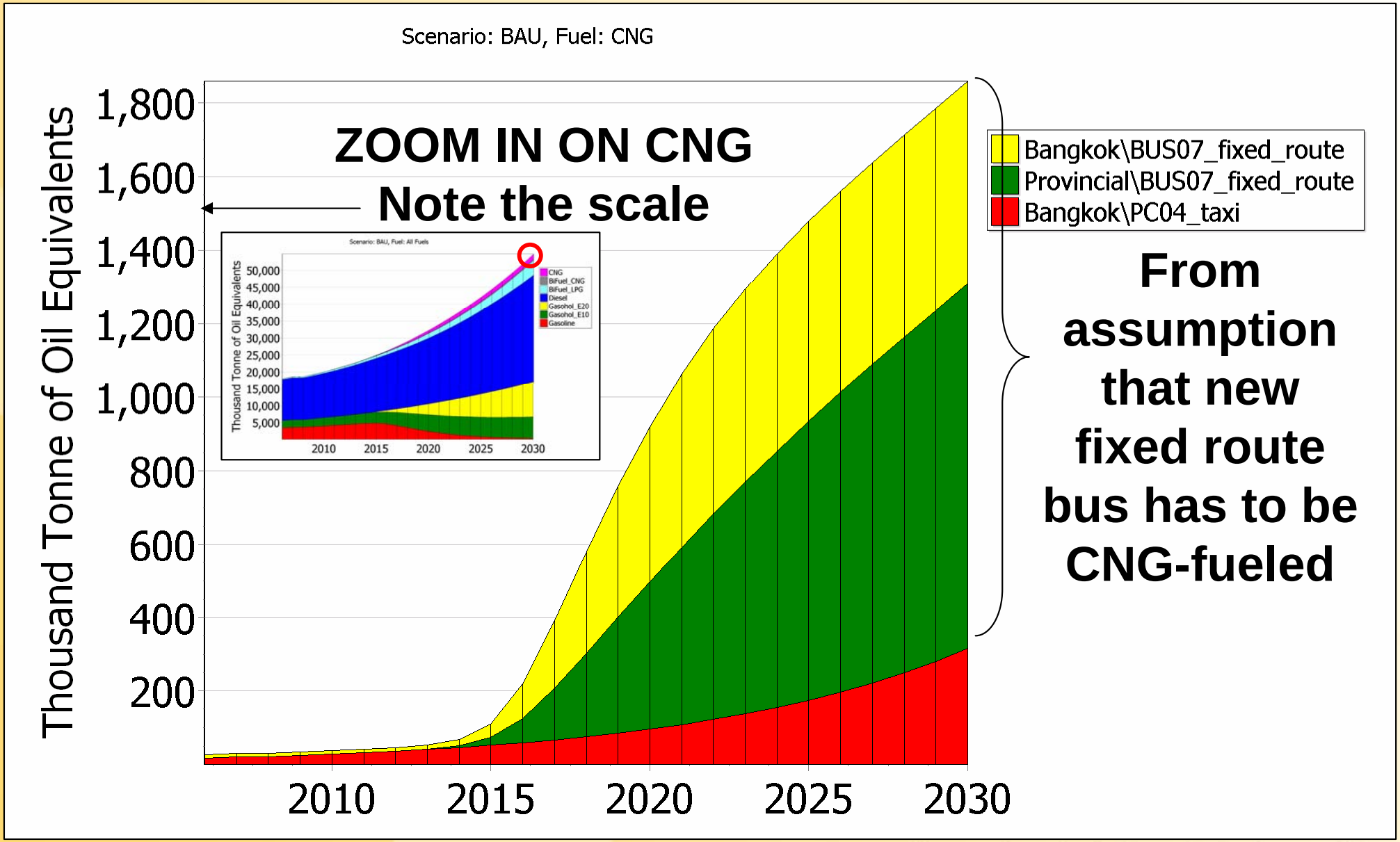
All fuel consumption by engine technology



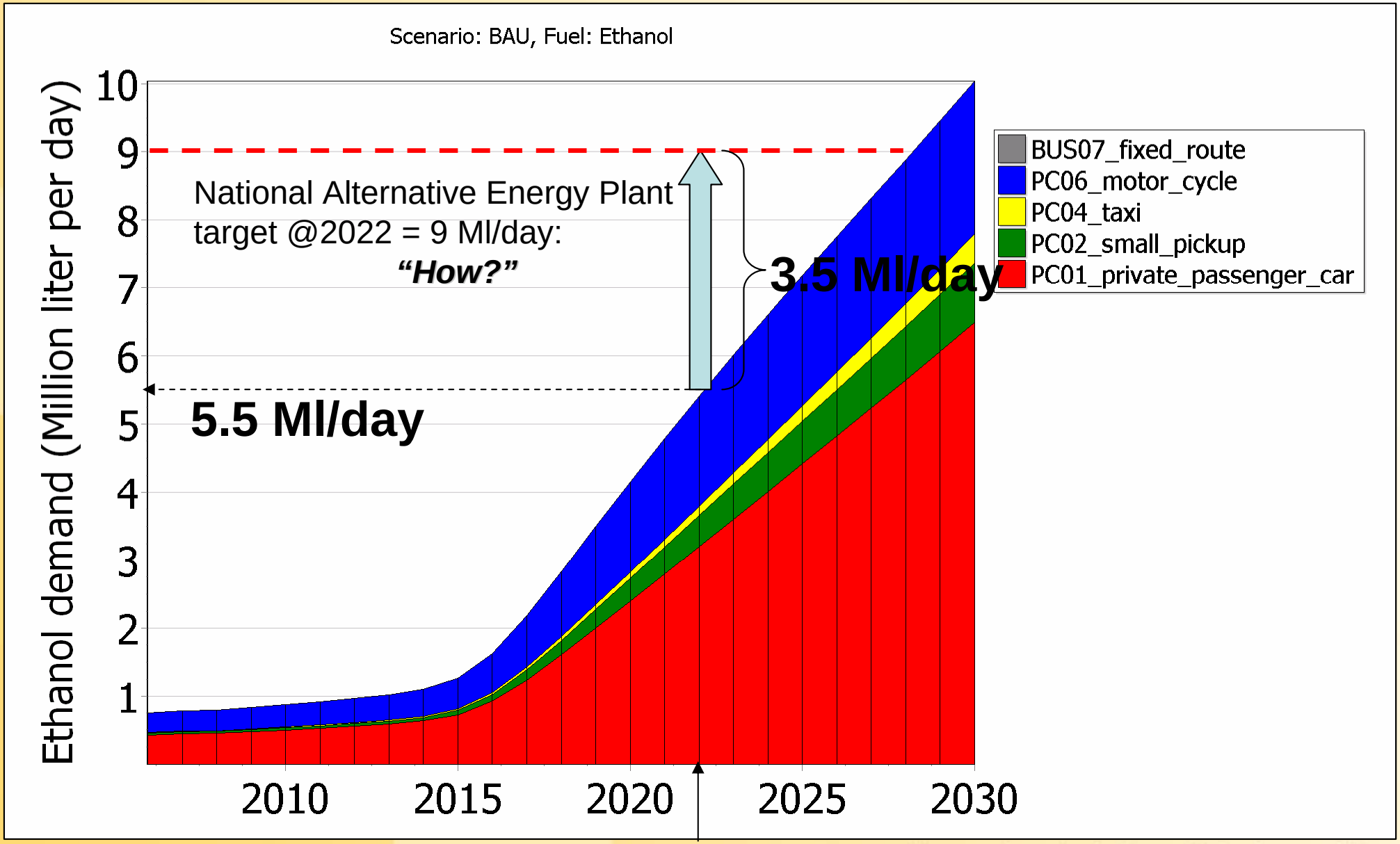
Diesel fuel consumption by vehicle type



CNG consumption by vehicle type

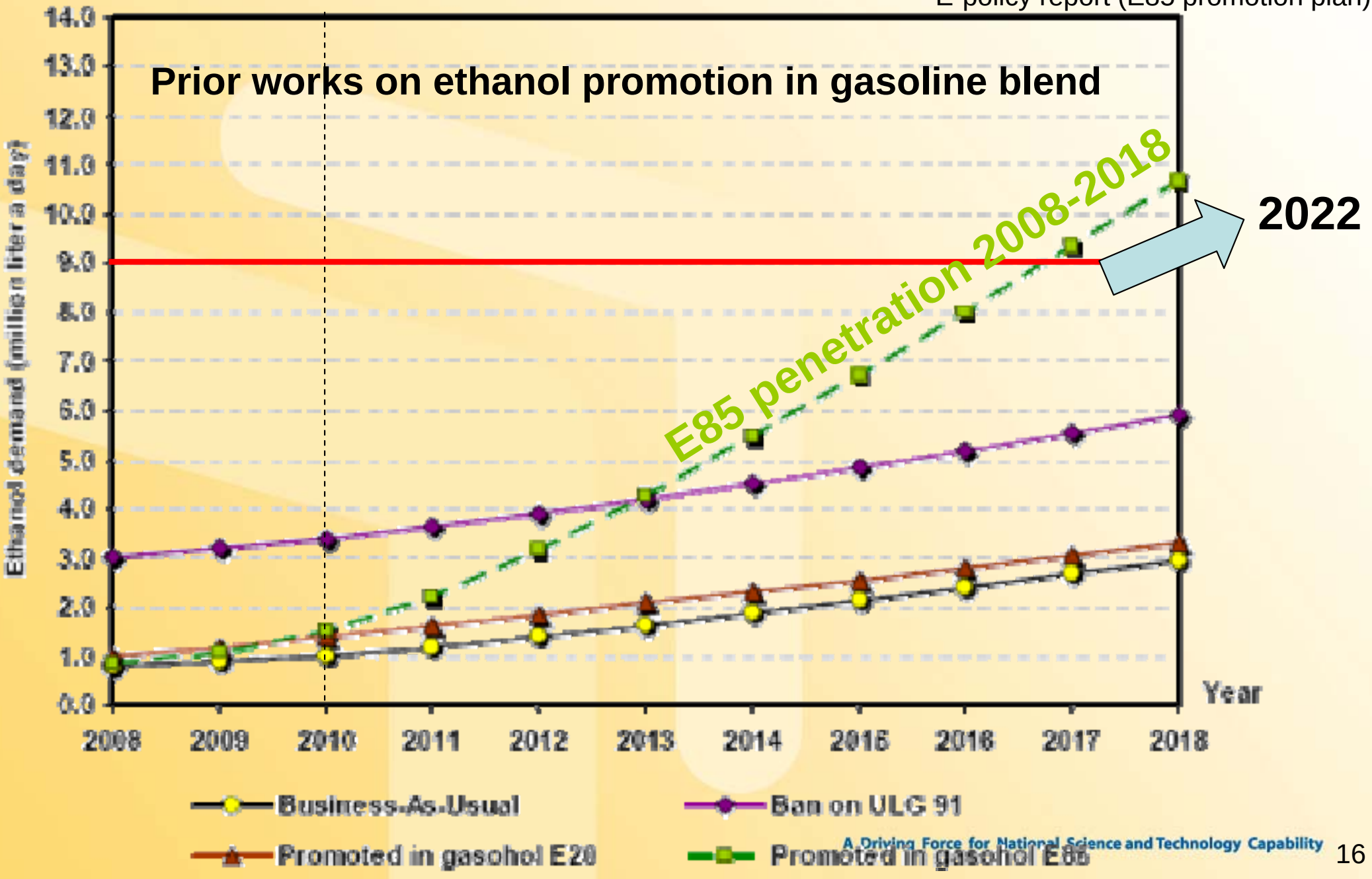


Ethanol consumption by vehicle type



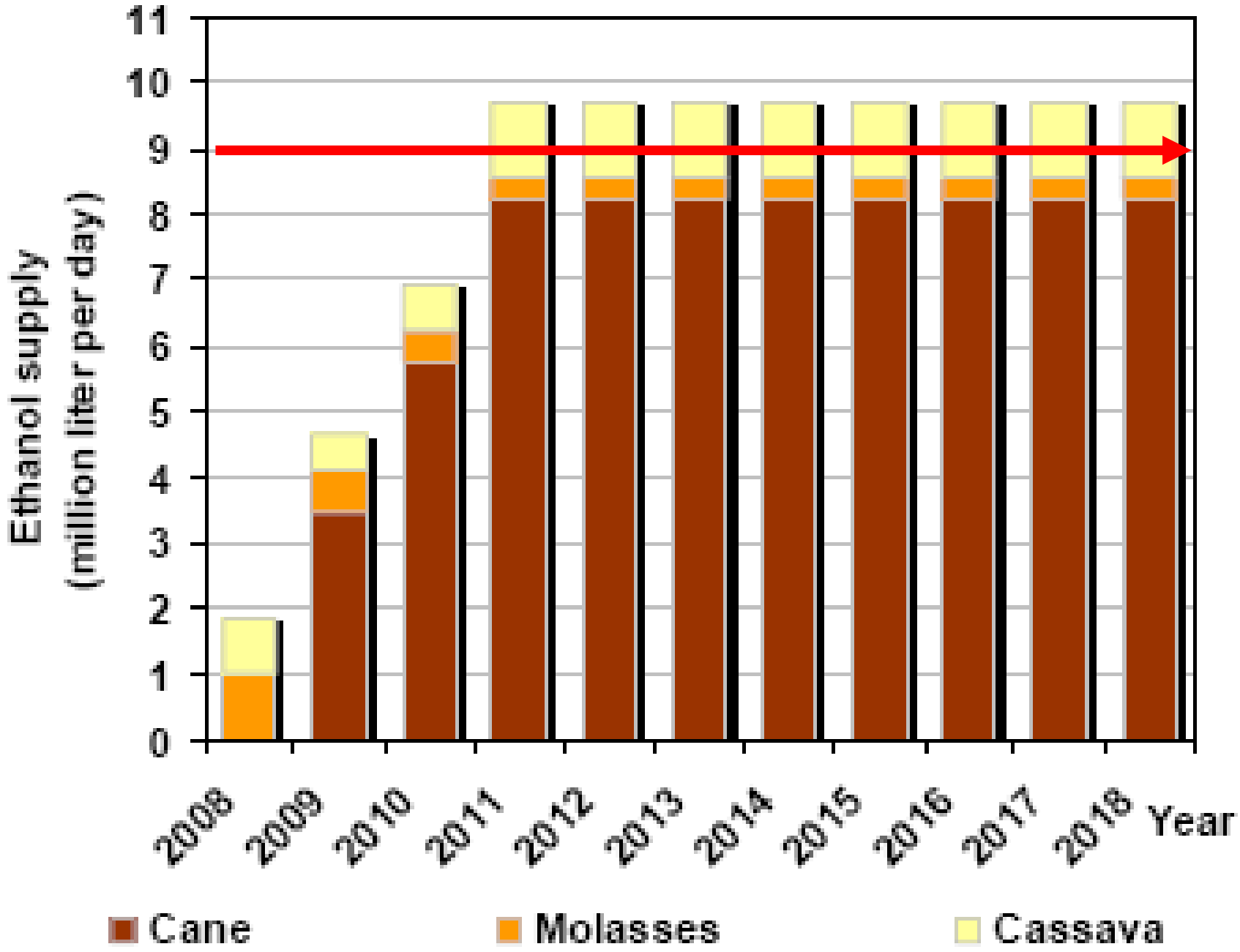
Ethanol promotion for gasoline substitute

E-policy report (E85 promotion plan)

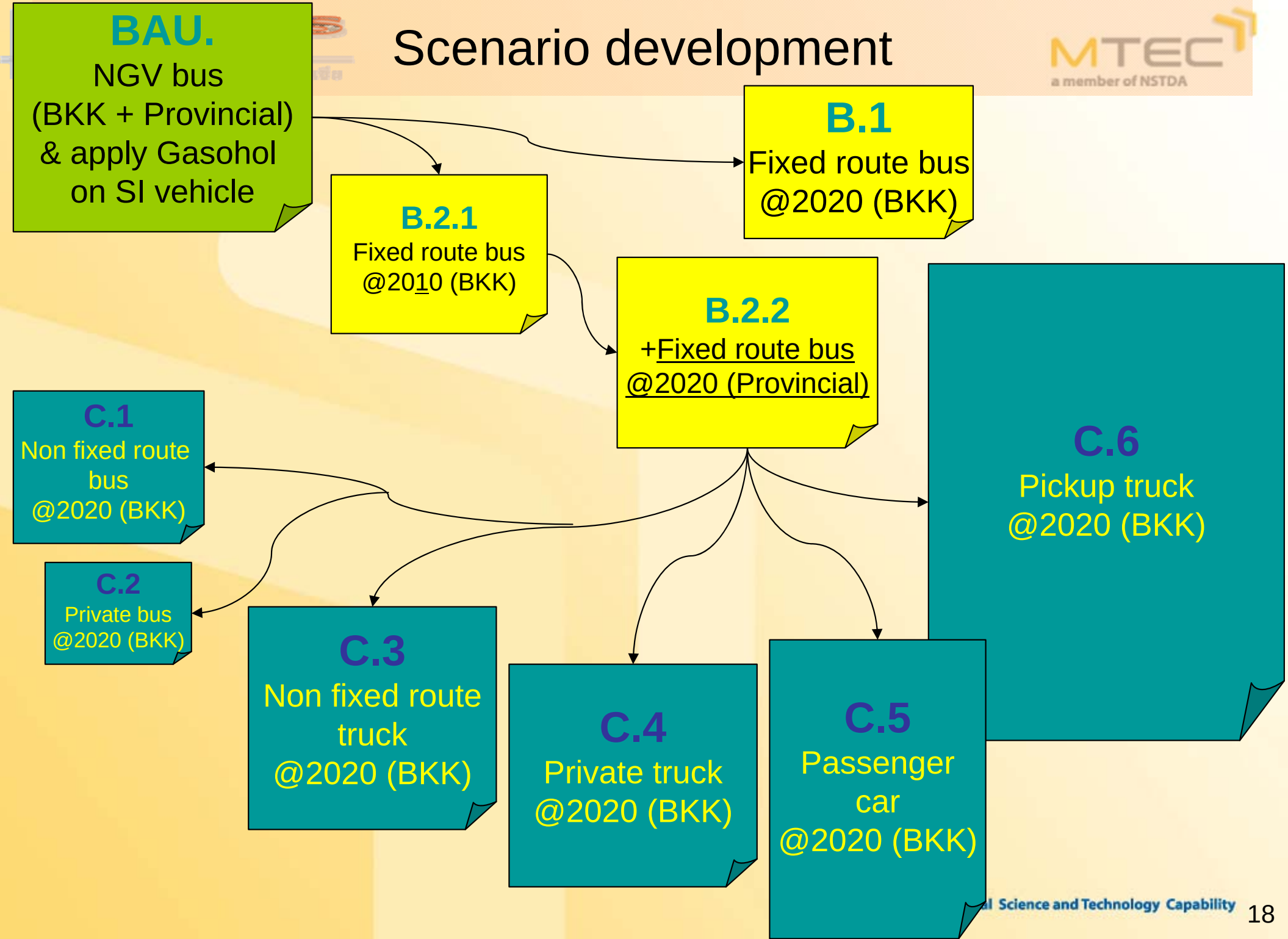


Estimation of ethanol supply

E-policy report



Scenario development



Scenario development

BAU.
NGV bus
(BKK + Provincial)
& apply Gasohol
on SI vehicle

B.1
e bus
KK)

Substitute NGV bus

+Fixed route bus
@2020 (Provincial)

C.1
Non fixed route
bus
@2020 (BKK)

C.6
Pickup truck
(BKK)

Substitute Diesel segment

truck
@2020 (BKK)

C.4
Private truck
@2020 (BKK)

Passenger
car
@2020 (BKK)

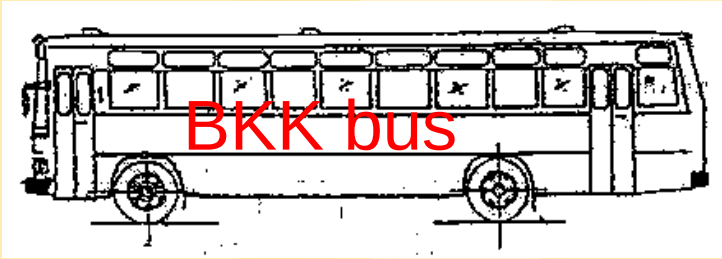
B.2.1 Replacing the NGV bus with ED95 bus in **Bangkok** area @2010

Model assumption

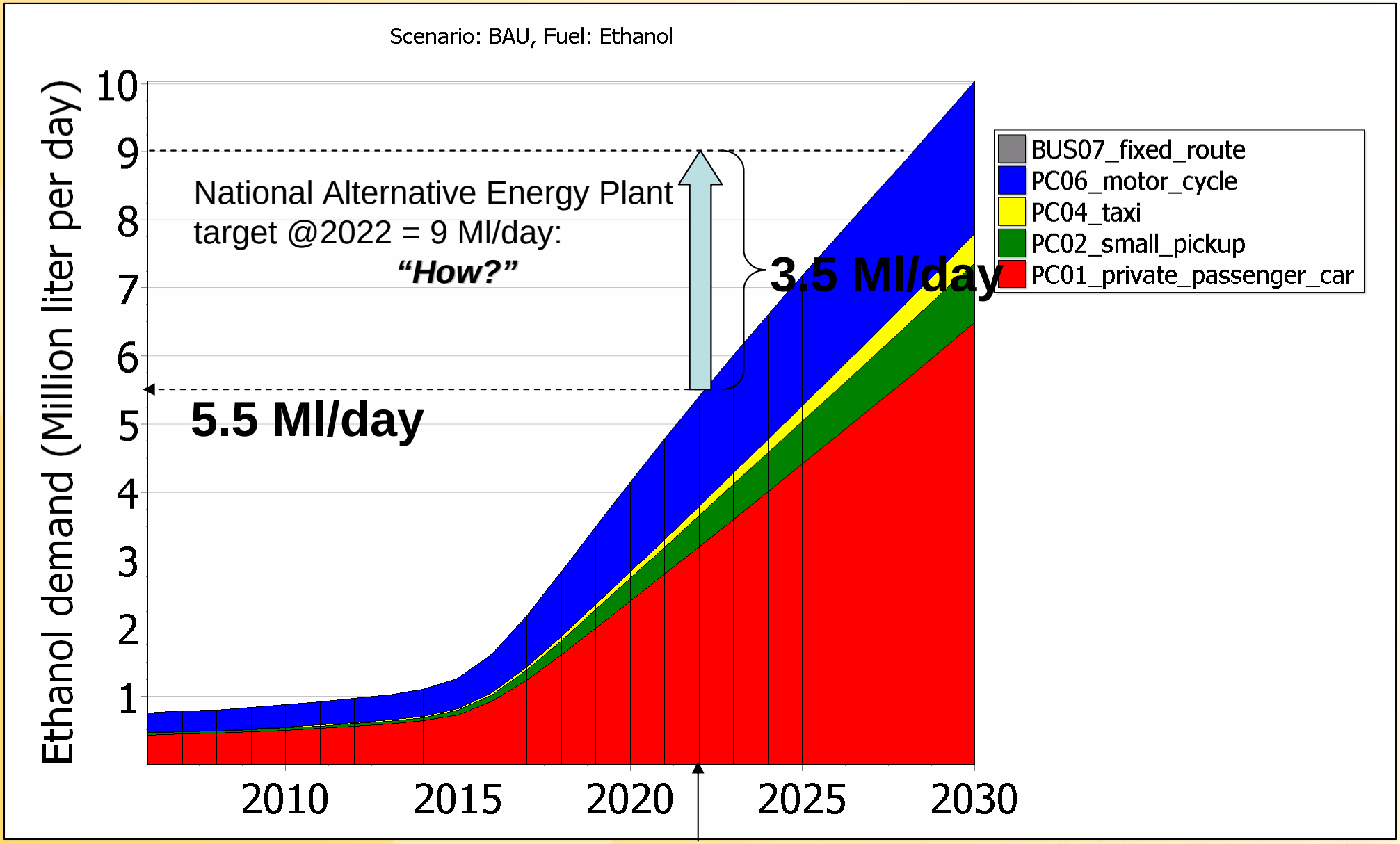
New SI car => E20 within 10 years

New SI motor-cycle => E10 within 10 years

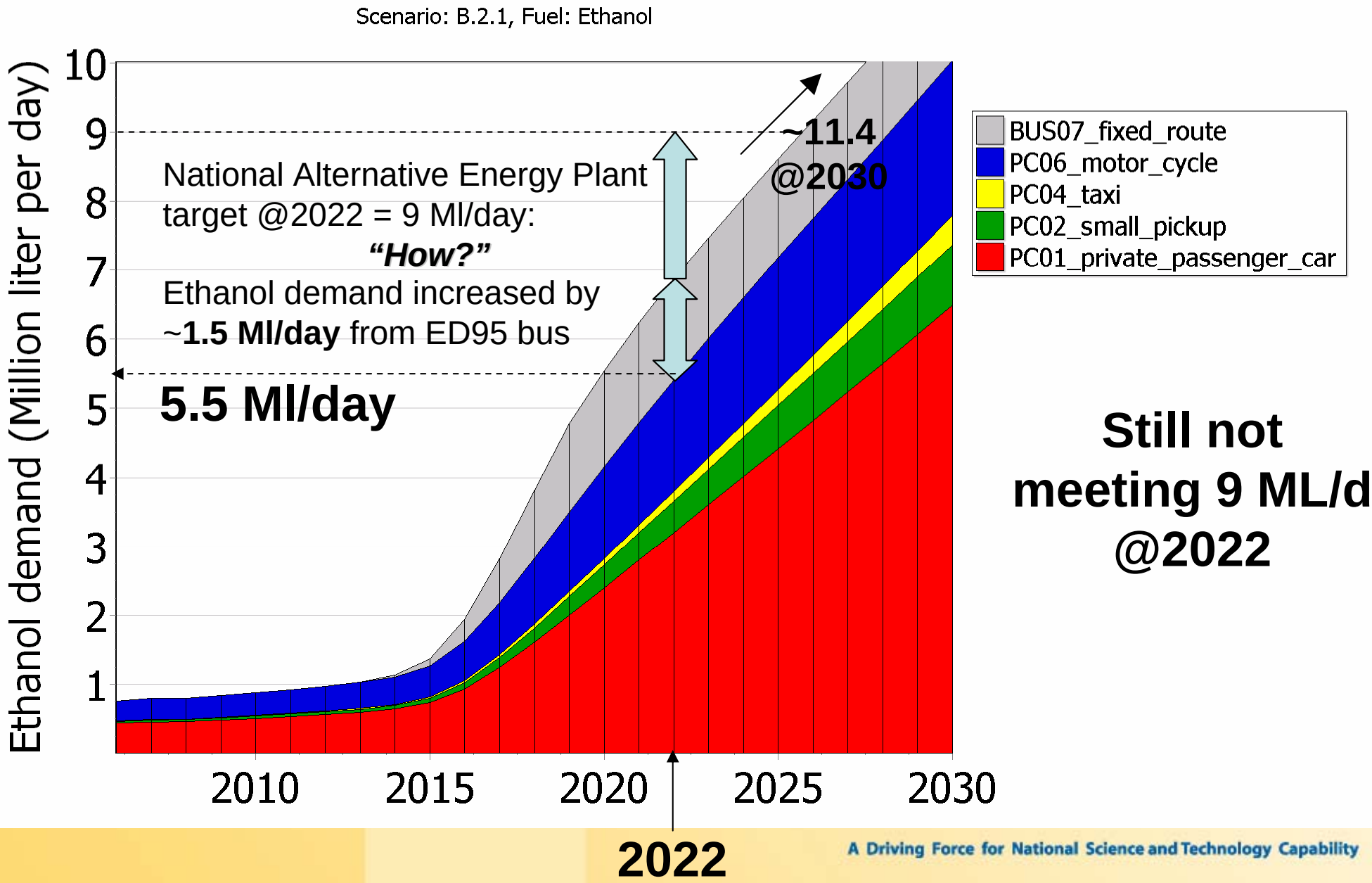
New fixed route bus => ED95 bus within 10 years



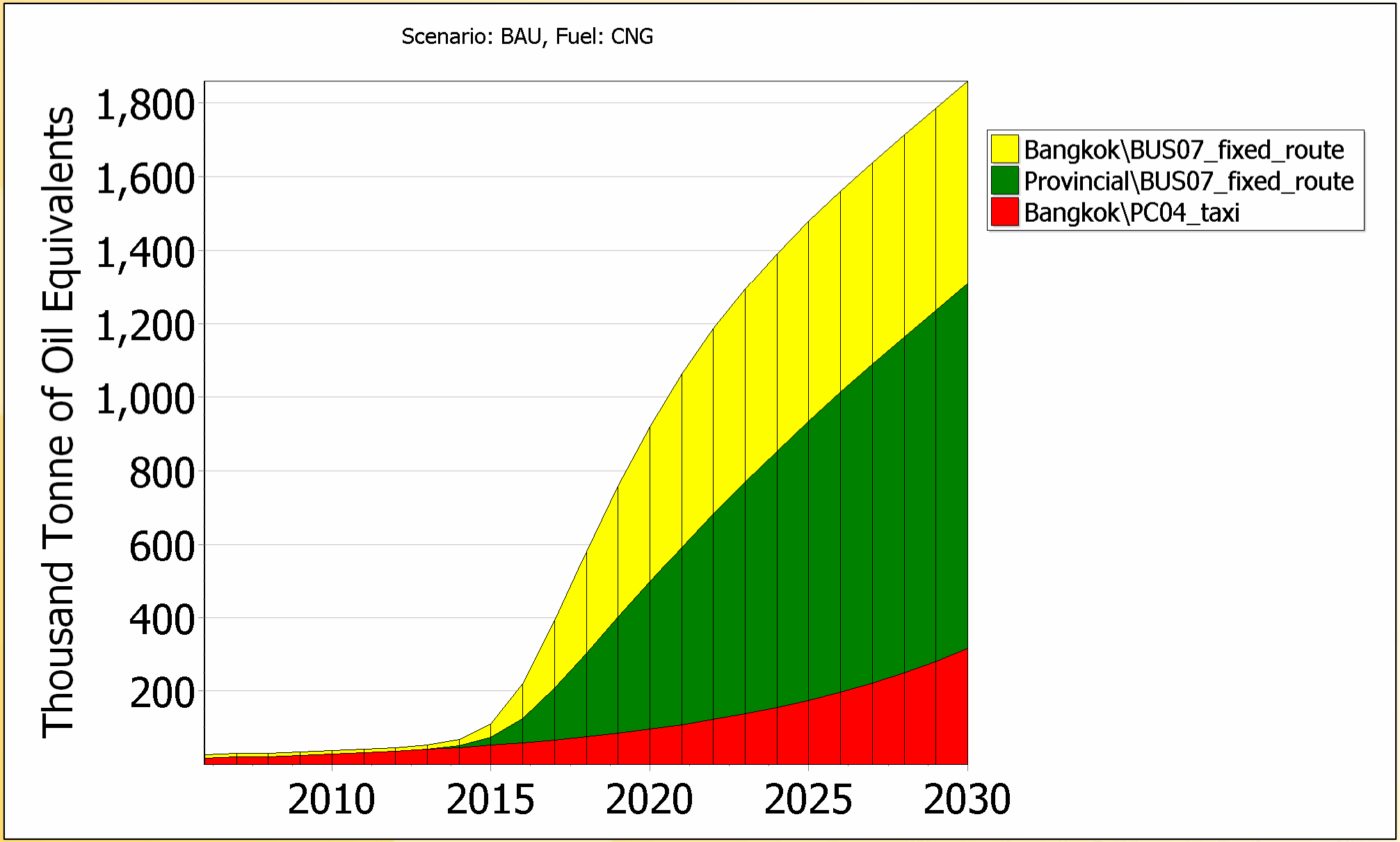
Ethanol consumption (BAU)



Applied ED95 bus on BMTA



CNG consumption (BAU)



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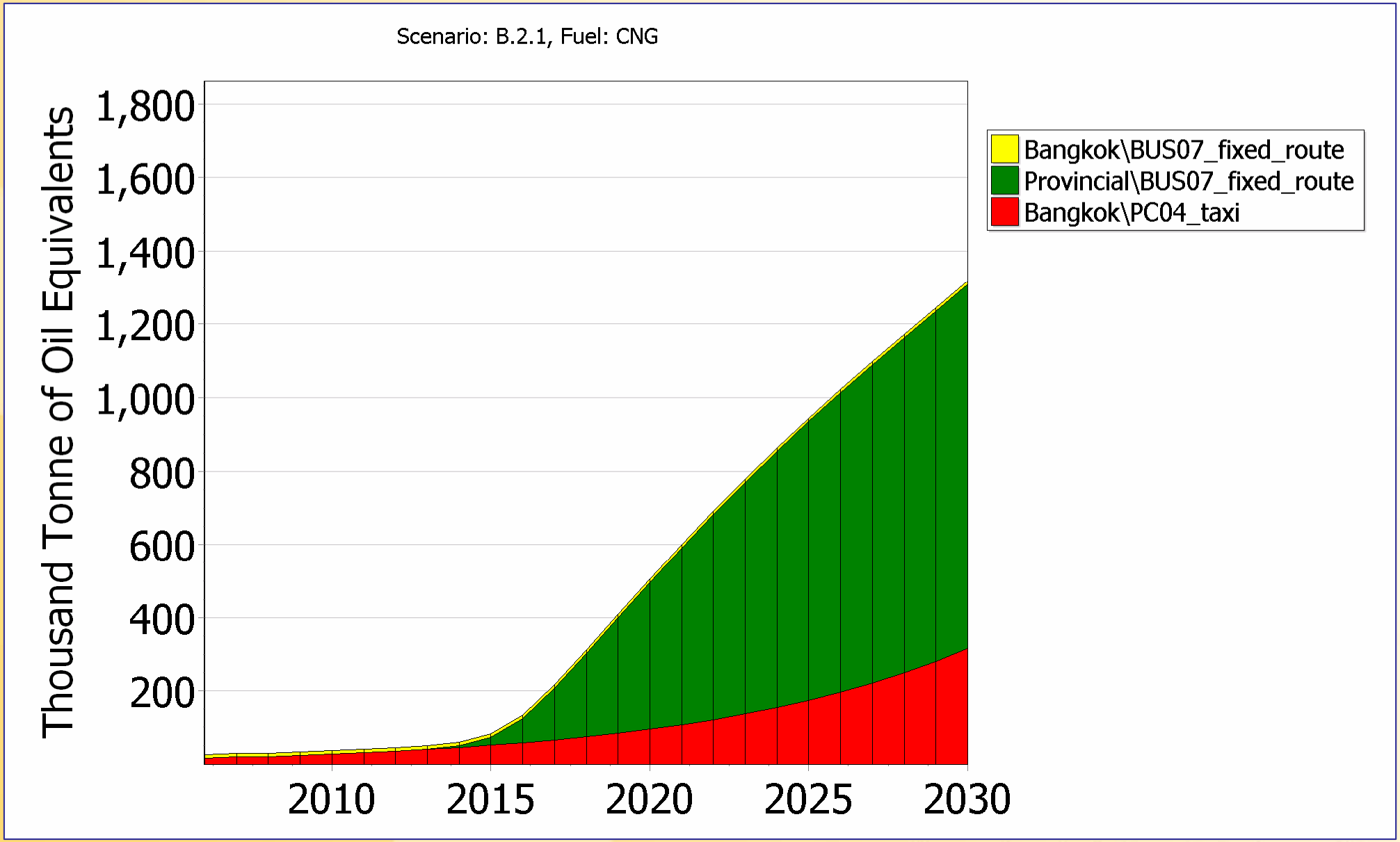


Greenhouse Gas (GHG) production calculation

$$EM = \sum_i EC \cdot EF_i \cdot GWP_i$$

EM = Emission (kg CO_2 equivalence)

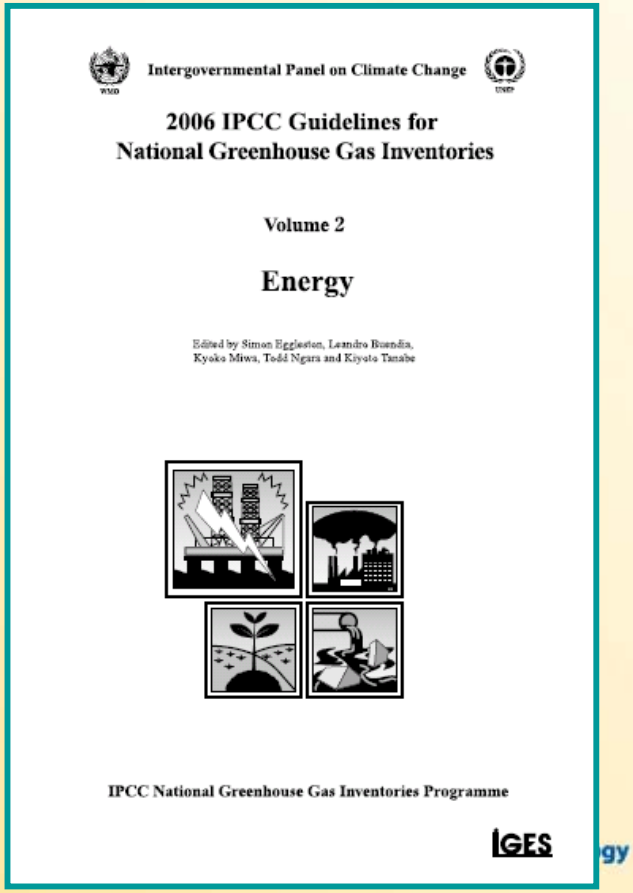
EC = Energy consumption (TJ)

EF_i = Emission factor of emission i (kg/TJ)

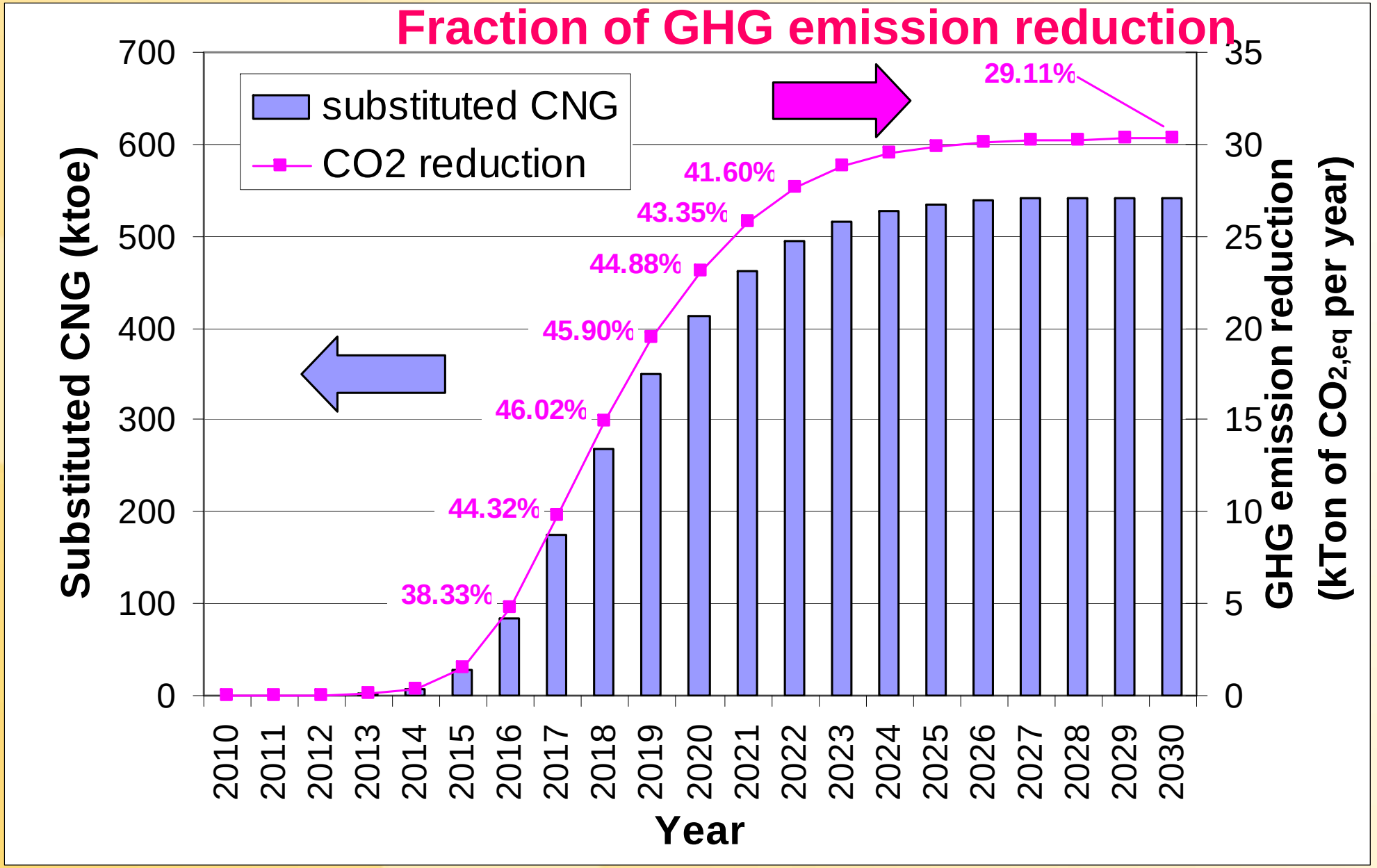
GWP_i = Global warming potential of emission i (g CO_2/g emission i)

i = Emission type, (CO_2, CH_4, N_2O)

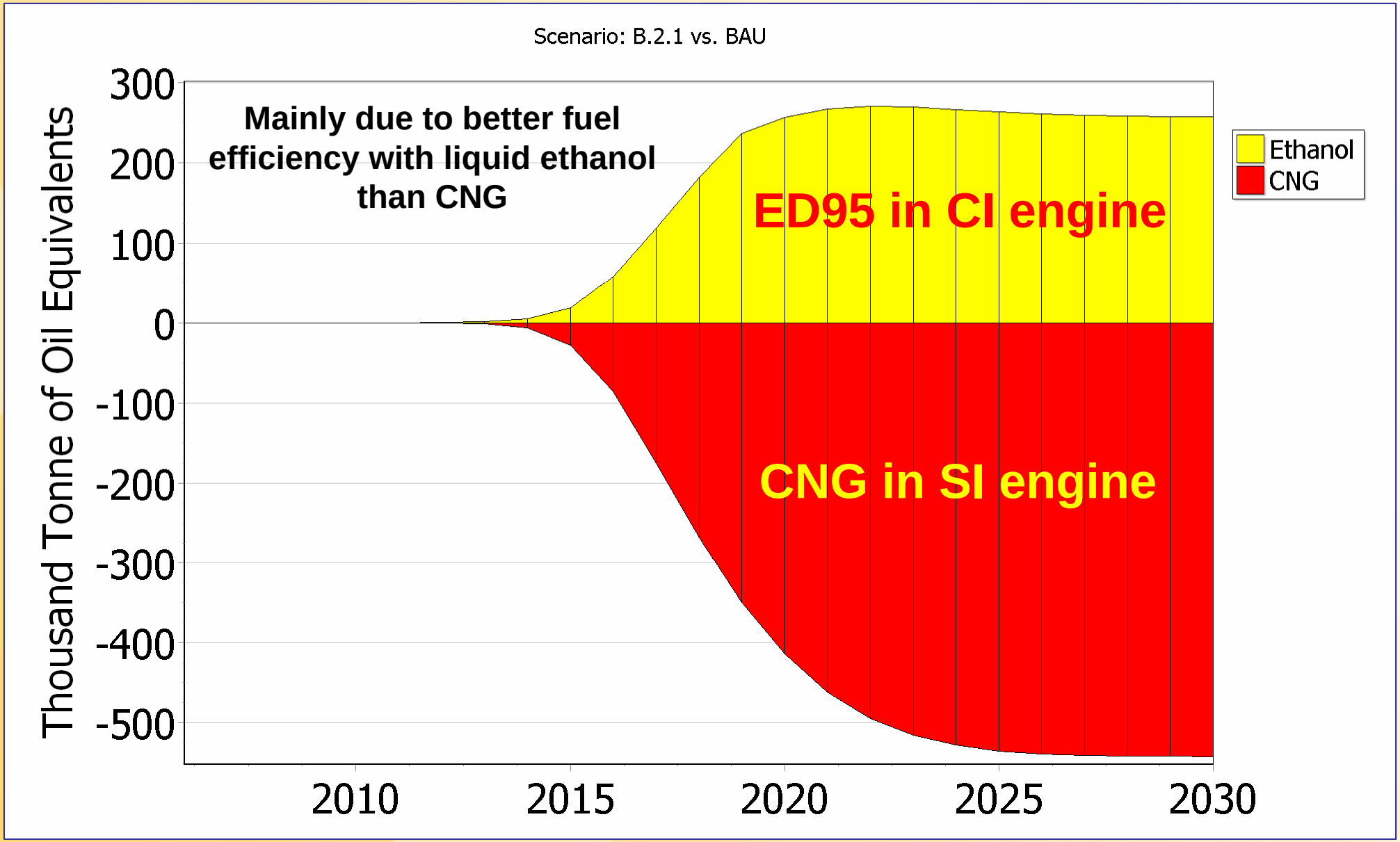
CNG fuel	CO_2	CH_4	N_2O
EF (kg/TJ)	55.5	50	0.1
GWP (gCO_2/g)	1	25	289



Effect from ED95 bus substitution



Impact on the Fuel Economy

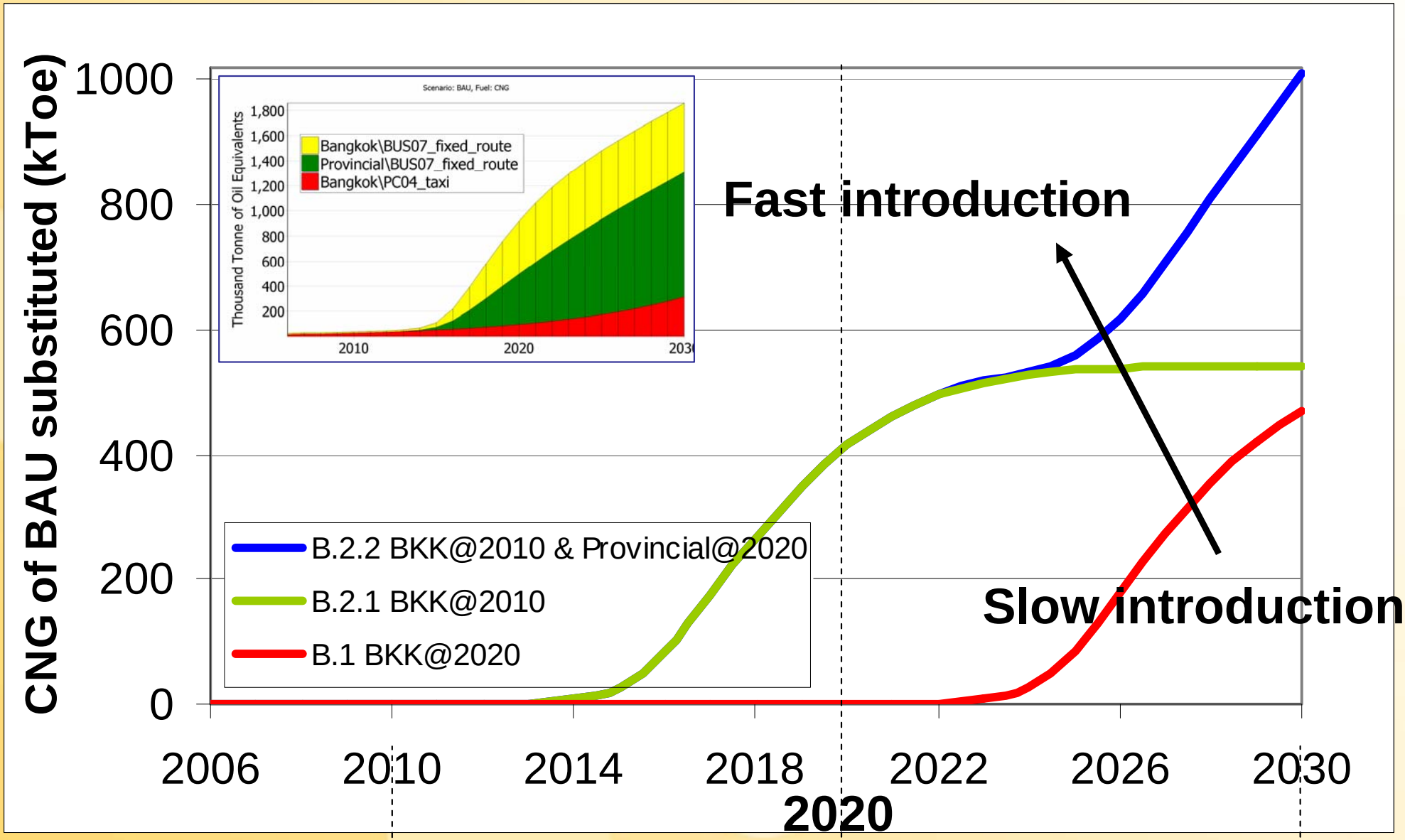


ATRANS
ASIAN TRANSPORTATION RESEARCH SOCIETY
สมาคมวิจัยวิทยาการขนส่งแห่งเอเชีย

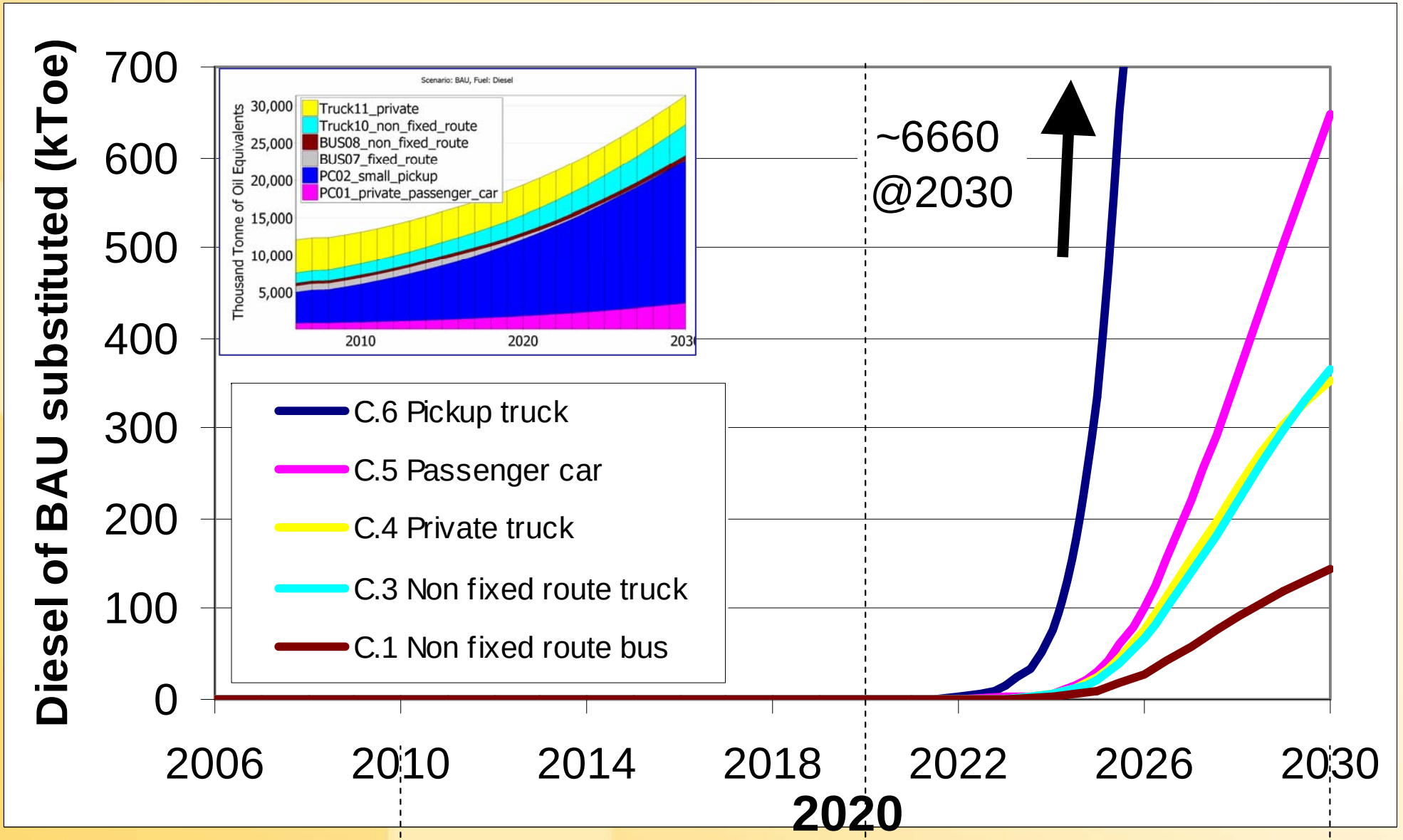
MTEC
a member of NSTDA

All Scenario Results

CNG substituted compared to BAU

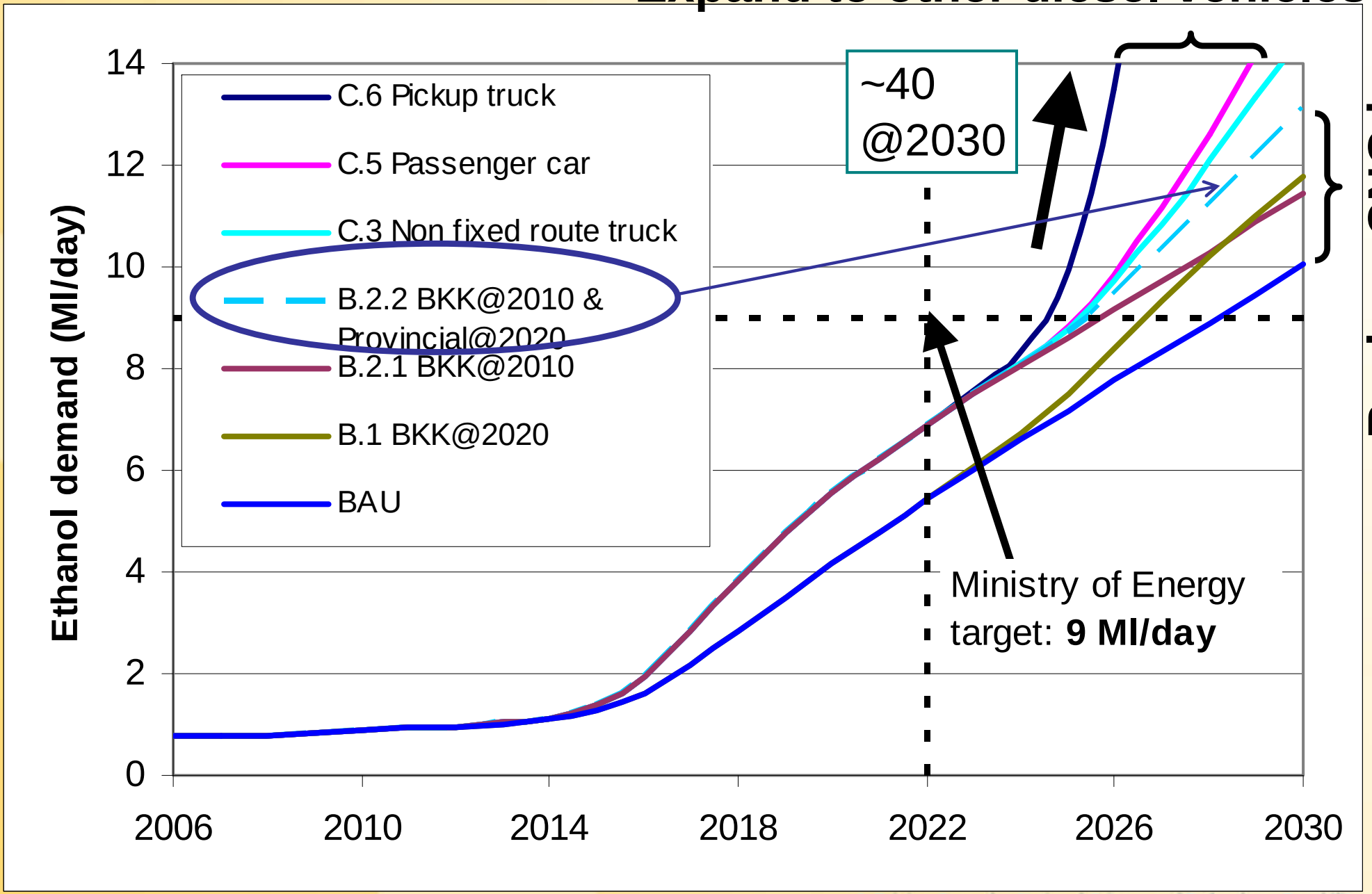


Diesel substituted compared to BAU



Ethanol demand (Million liter per day)

Expand to other diesel vehicles



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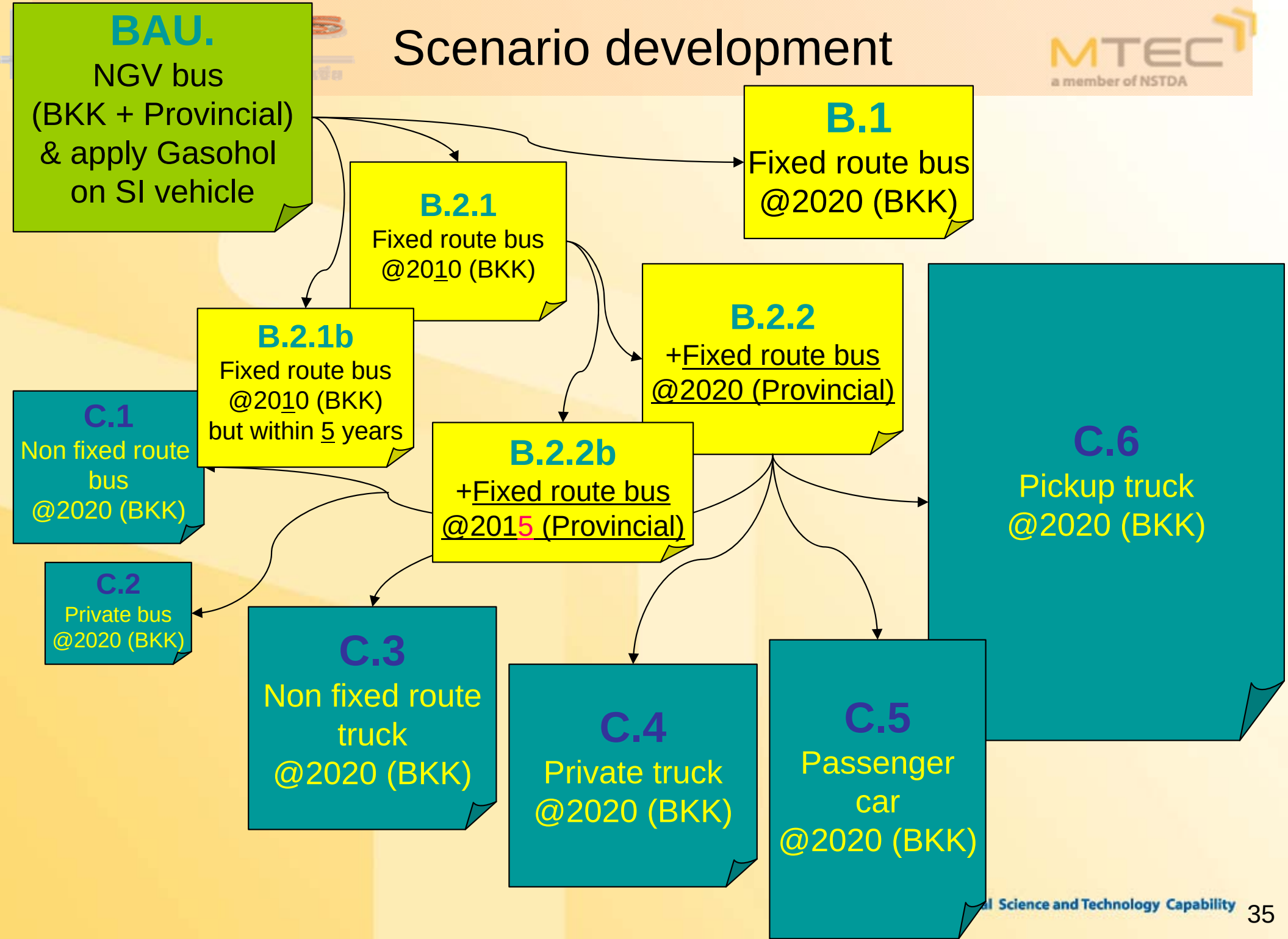
Conclusions & Recommendation

- Conclusions
  - ED95 technology in CI engine can be employed to increase ethanol demand toward the 9 Ml/day target in National Alternative Energy Plan
  - In addition, ED95 helps reduce GHG emission that would have been emitted from CNG bus (due to carbon neutral ethanol)
  - With ED95 technology in CI engine, better fuel efficiency can be achieved compared to CNG in SI engine.
  - ED95 technology helps enhance energy security in the country

- Recommendation
  - Even with strong introduction of ED95 technology in CNG and diesel vehicle, a target of 9 Ml/day ethanol consumption is still challenging → need to be integrated with the measure to increase ethanol consumption in gasoline market (SI engine)


Thank you…
Comments & Remarks

Scenario development



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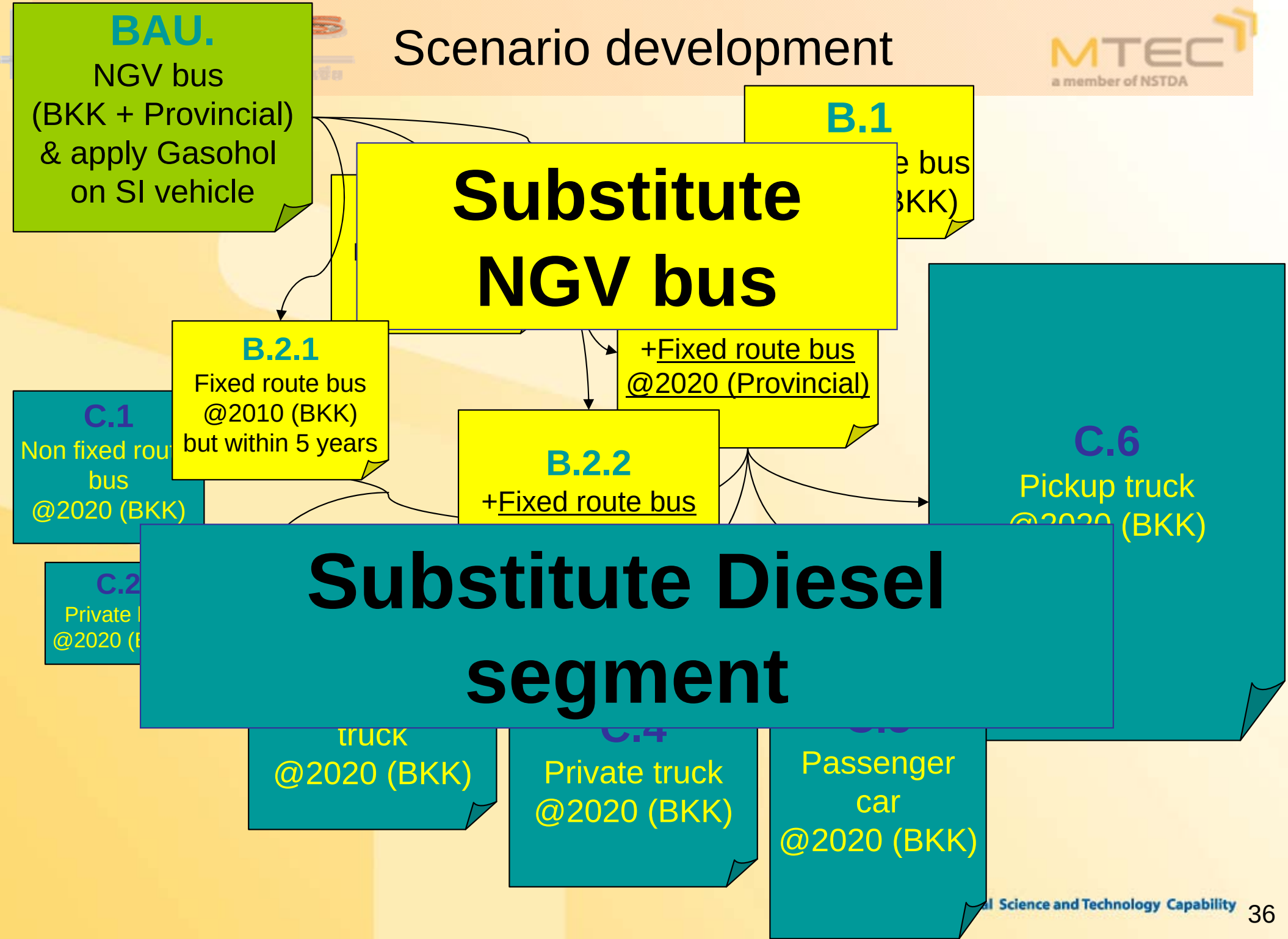

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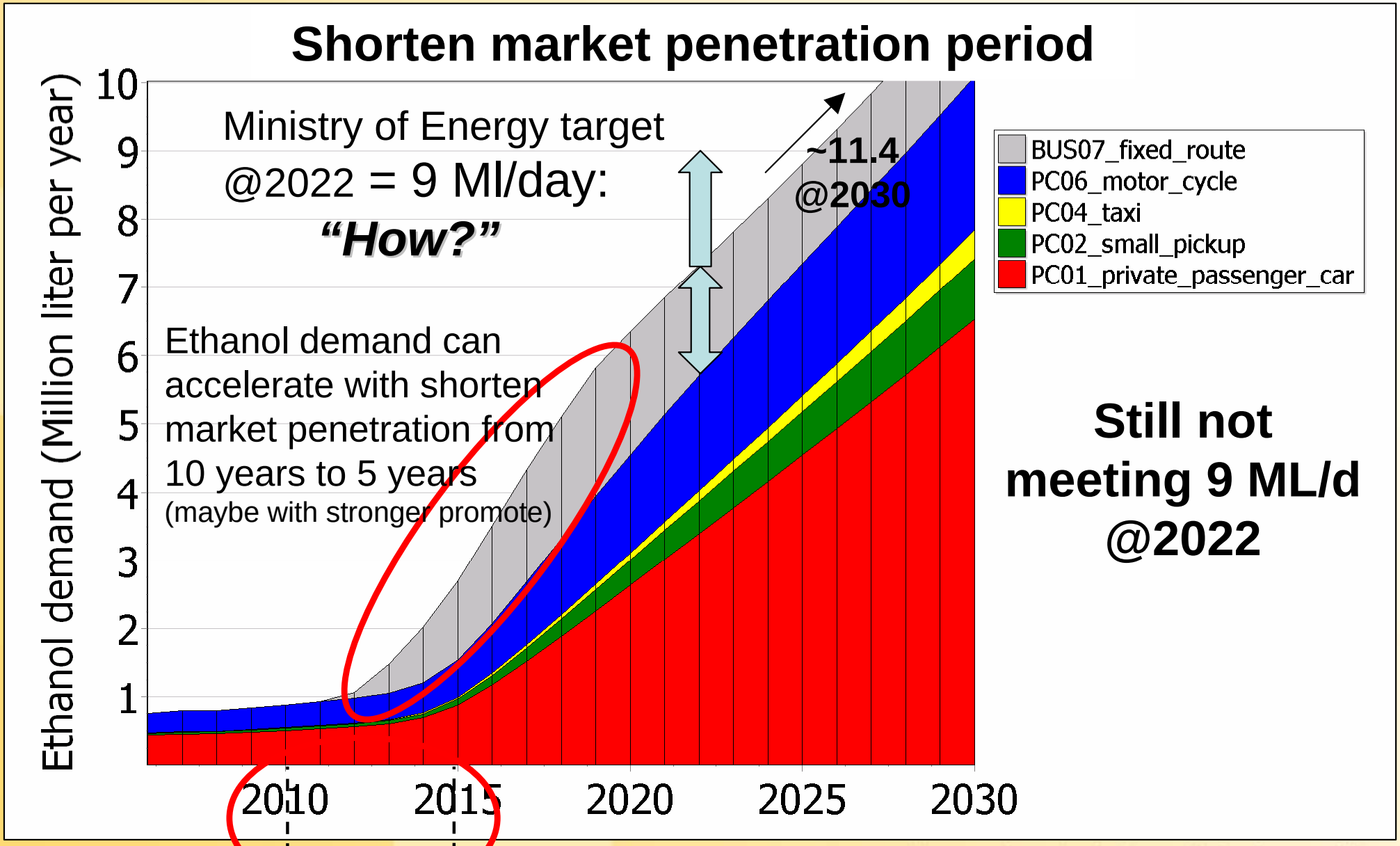

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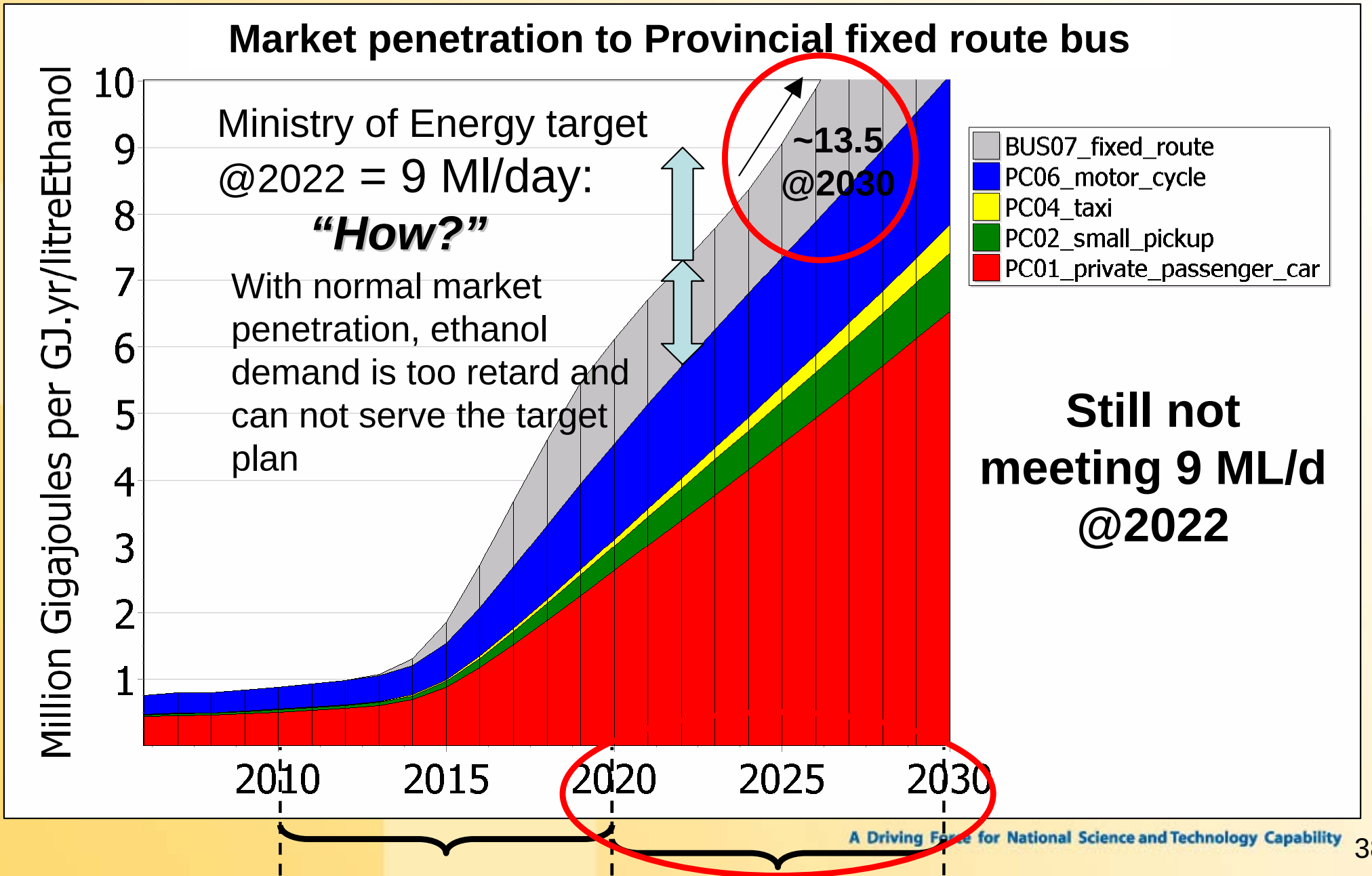

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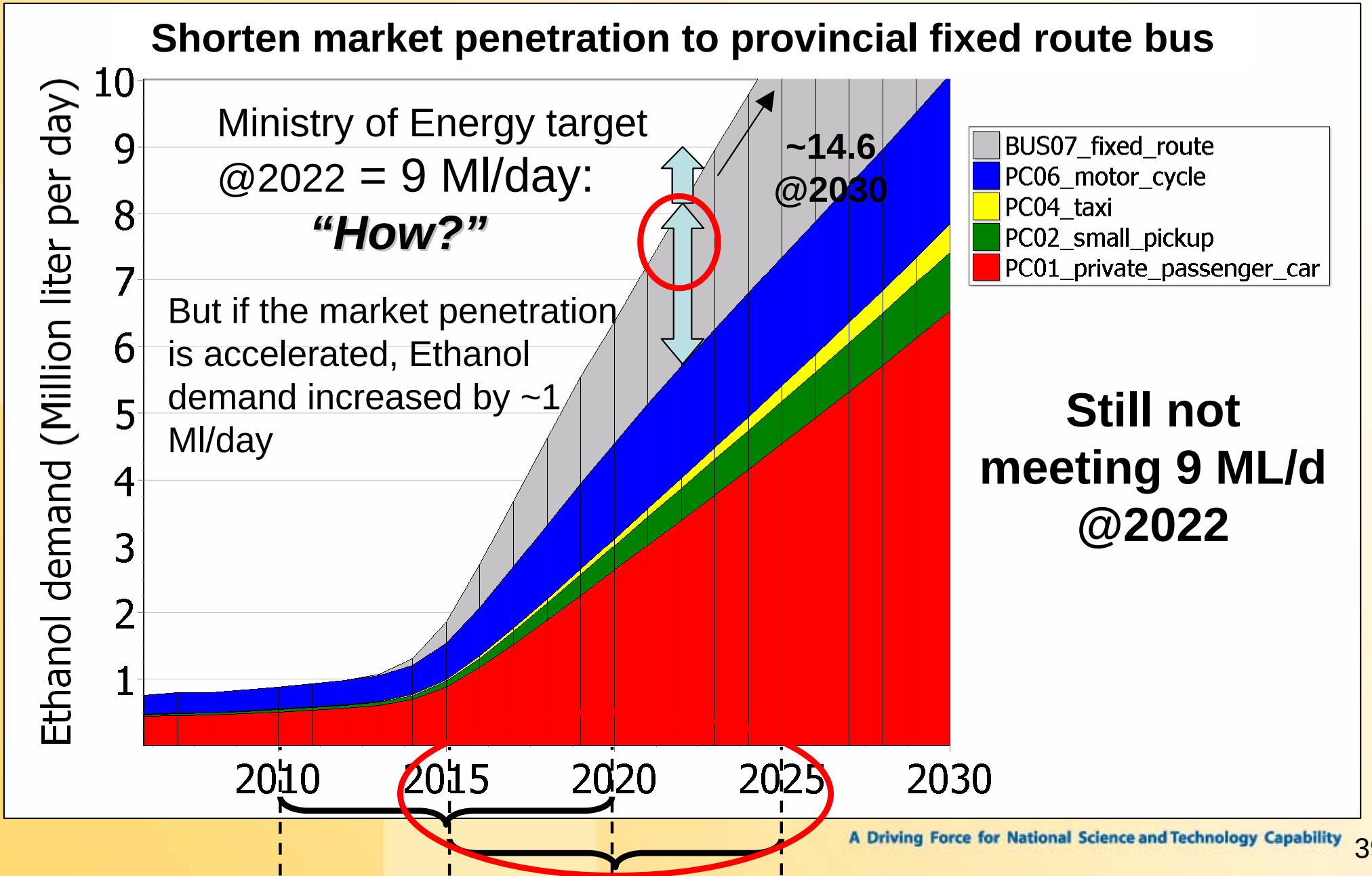
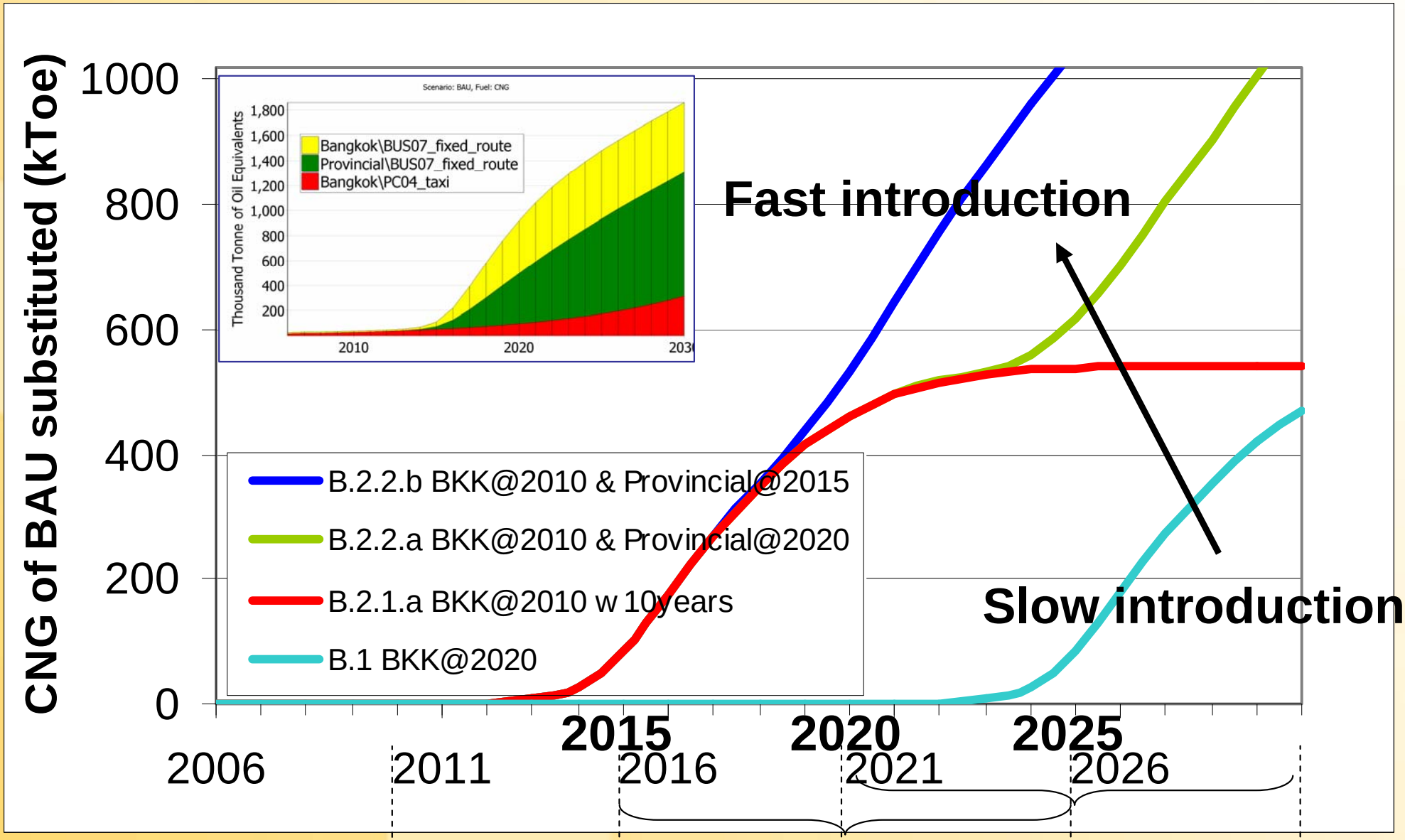
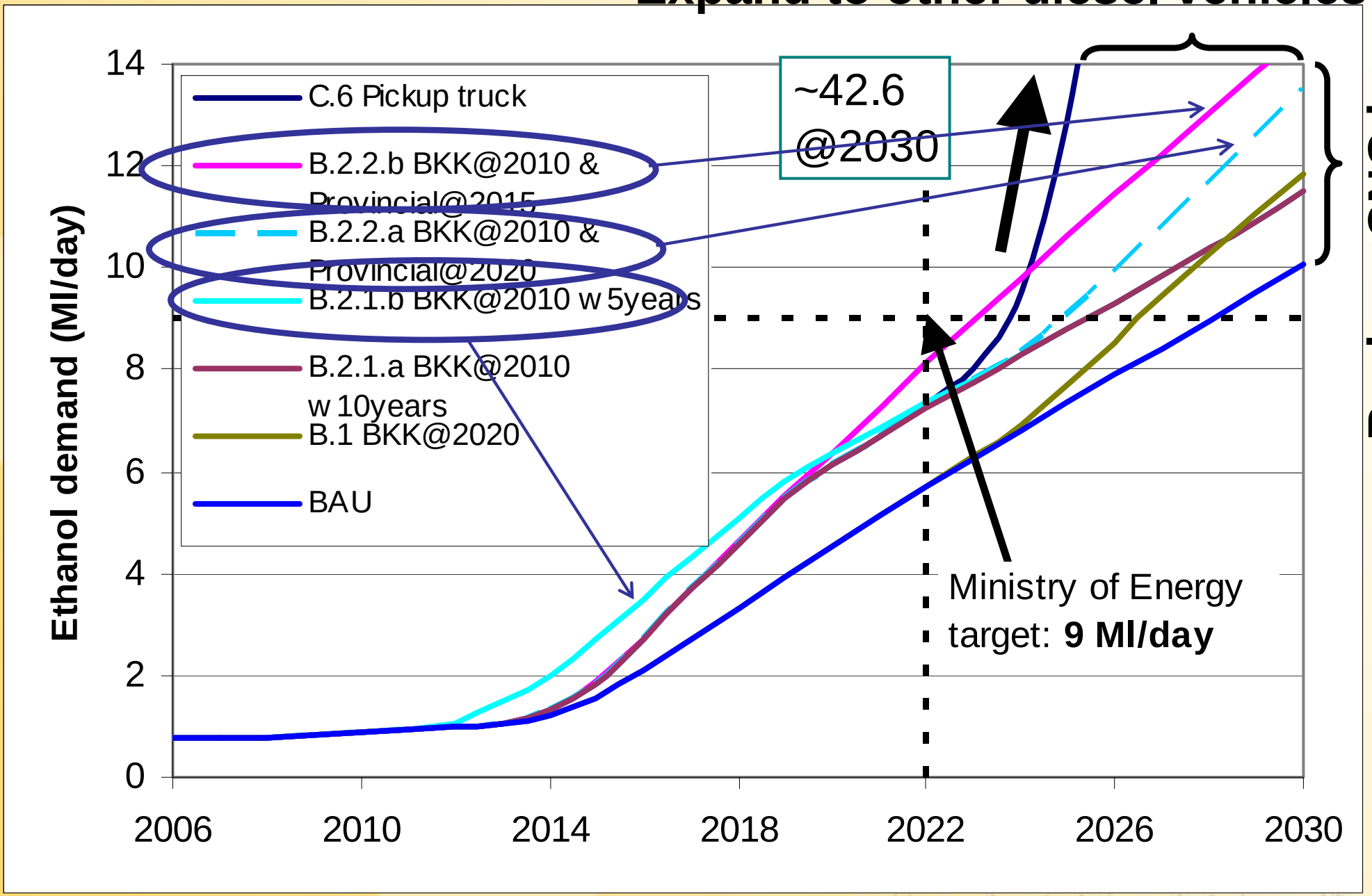


CNG substituted refer to BAU



Ethanol demand (Million liter per day)

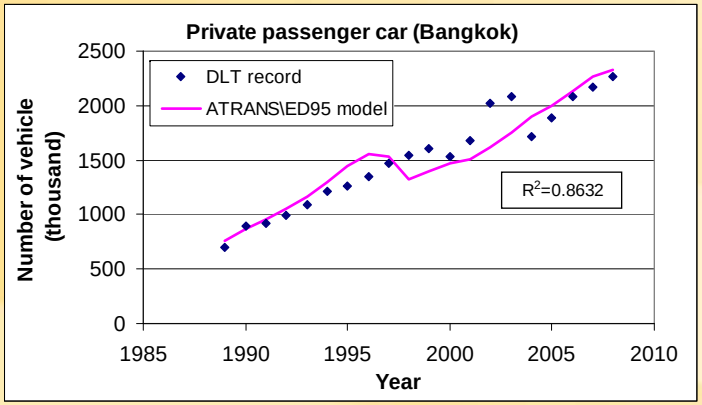
Expand to other diesel vehicles

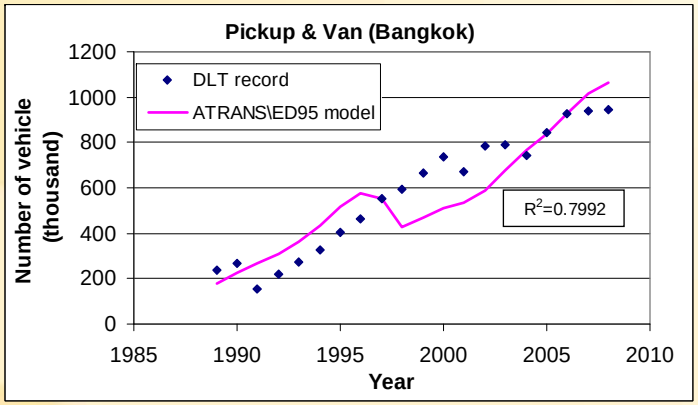


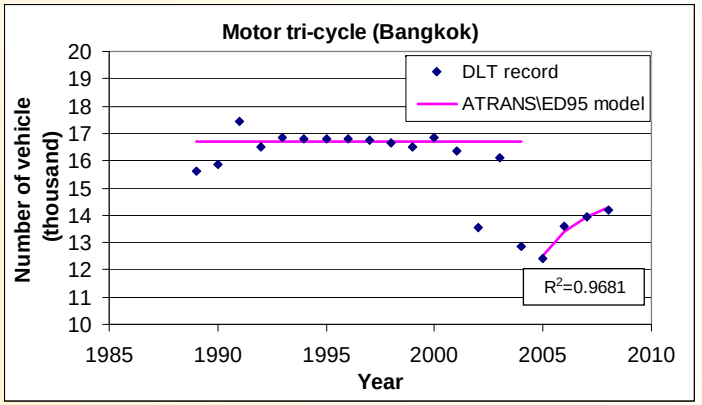
Vehicle type

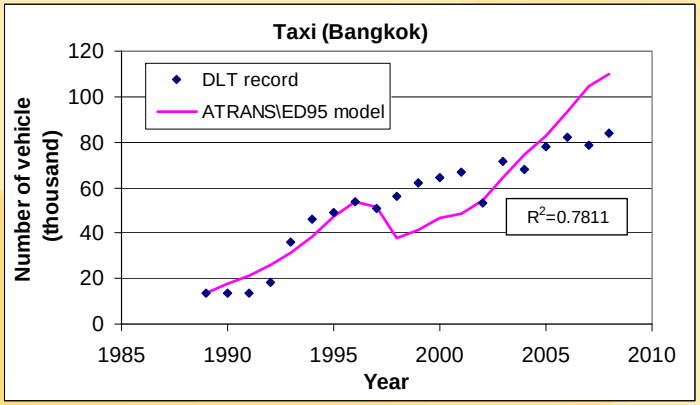
A. Total vehicle under motor vehicle act		B. Total vehicle under land transport act	
MV.1 Not more than 7 passengers	PC01 passenger car	Bus	
MV.2 Microbus & Passenger Van		- Fixed Route Bus	BUS01 Fixed route bus
MV.3 Van & Pick Up	PC02 pickup	- Non Fixed Route Bus	BUS02 Non fixed route bus
MV.4 Motortricycle	PC03 motor tri-cycle	- Private Bus	BUS03 Private bus
MV.7 Fixed Route Taxi (Subaru)		Small Rural Bus	sBus04 Small bus
MV.8 Motortricycle Taxi (Tuk Tuk)		Truck	
MV.6 Urban Taxi	PC04 taxi	- Non Fixed Route Truck	Truck01 Non fixed route truck
MV.5 Interprovincial Taxi	PC05 Commercial rent car	- Private Truck	Truck02 Private truck
MV.9 Hotel Taxi			
MV.10 Tour Taxi			
MV.11 Car for Hire			
MV.12 Motorcycle	PC06 Motor cycle		
MV.17 Public Motorcycle			
MV.13 Tractor	-		
MV.14 Road Roller			
MV.15 Farm Vehicle		record from DLT (Dec2009)	
MV.16 Automobile Trailer		http://apps.dlt.go.th/statistics_web/statistics.html	

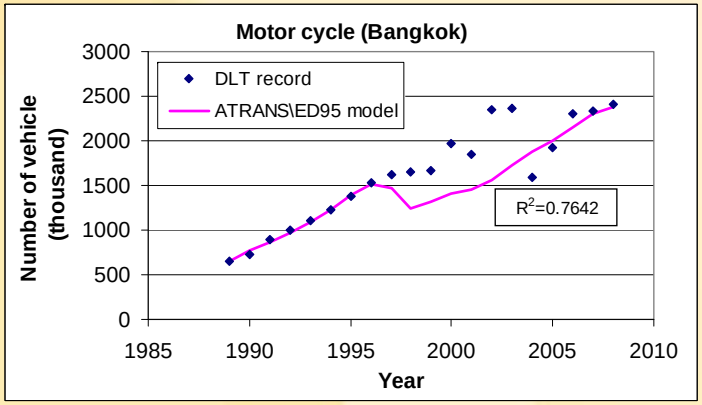
Number of vehicle in Bangkok

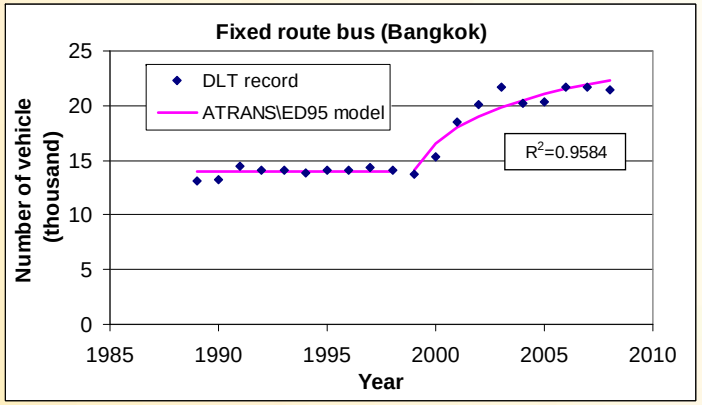


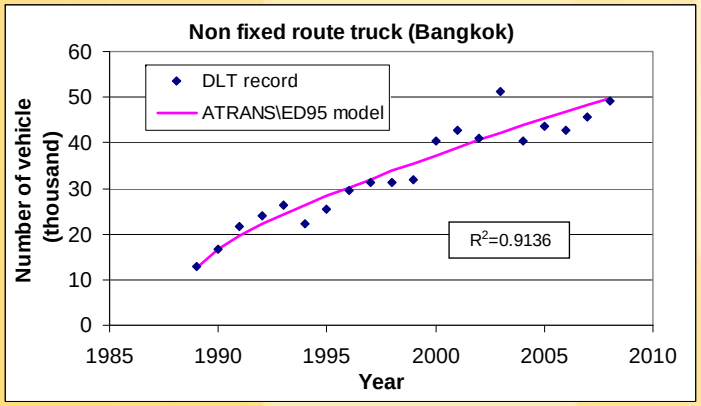


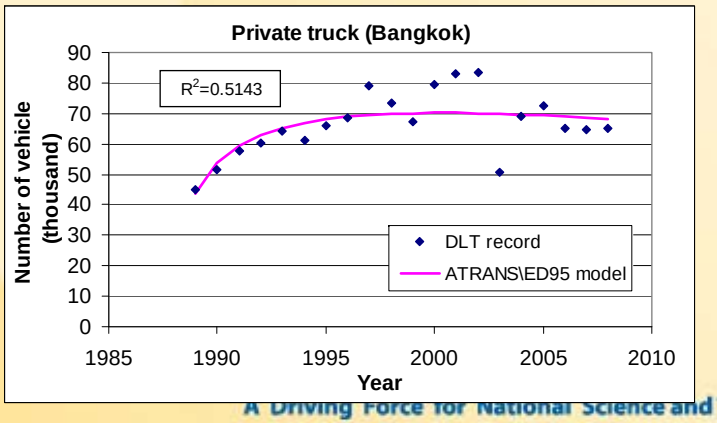




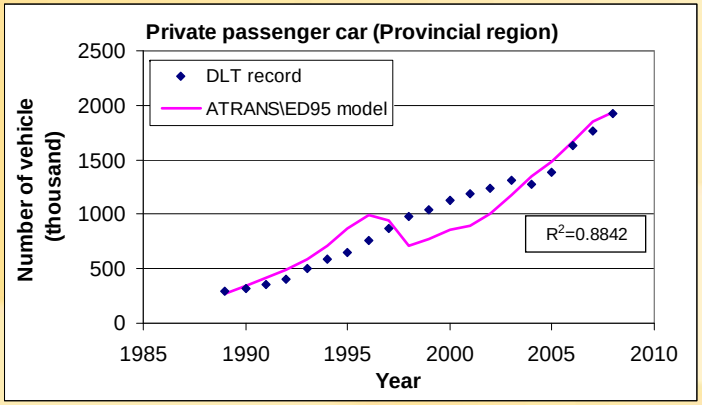


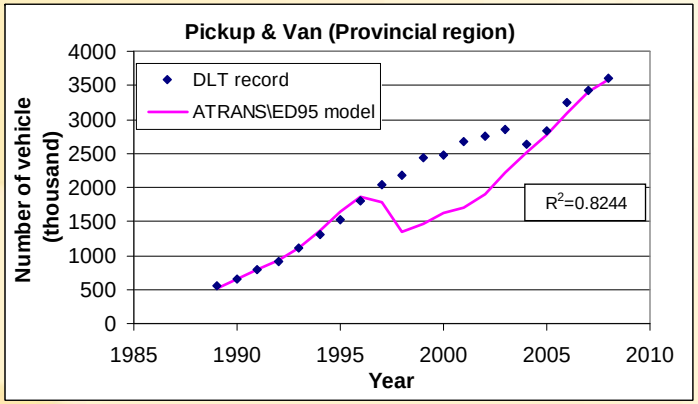


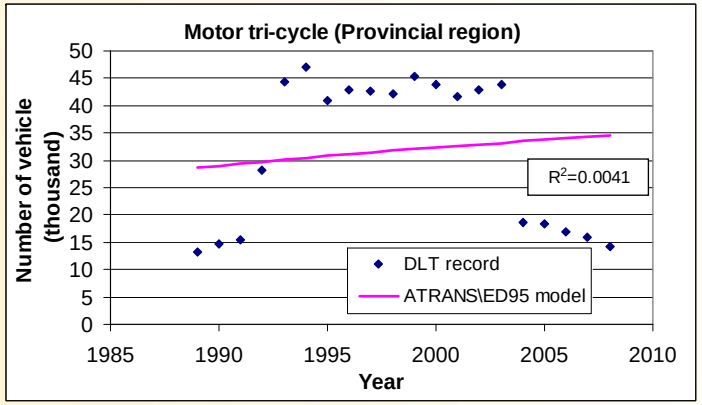


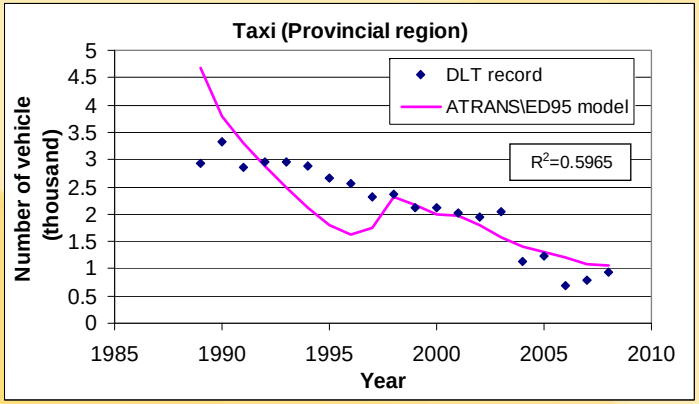


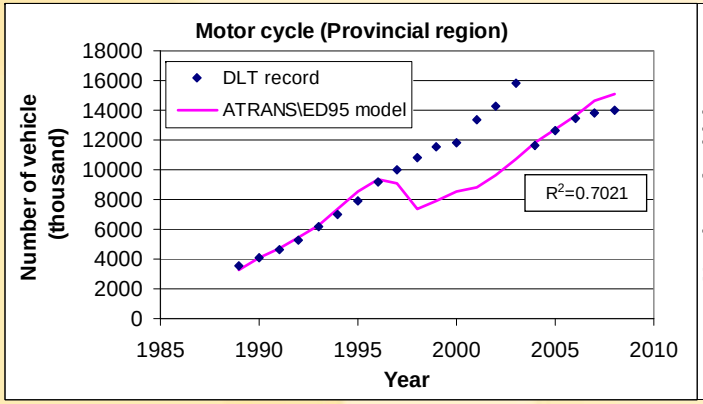
Number of vehicle in provincial region

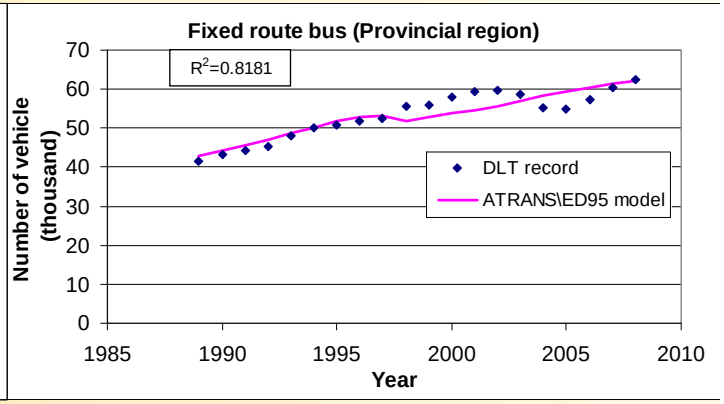


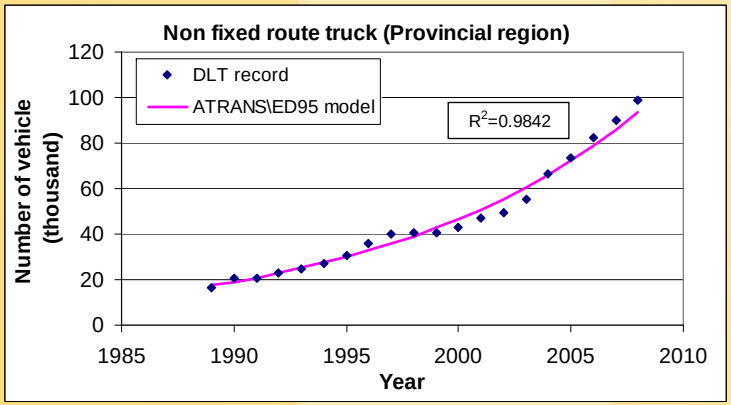


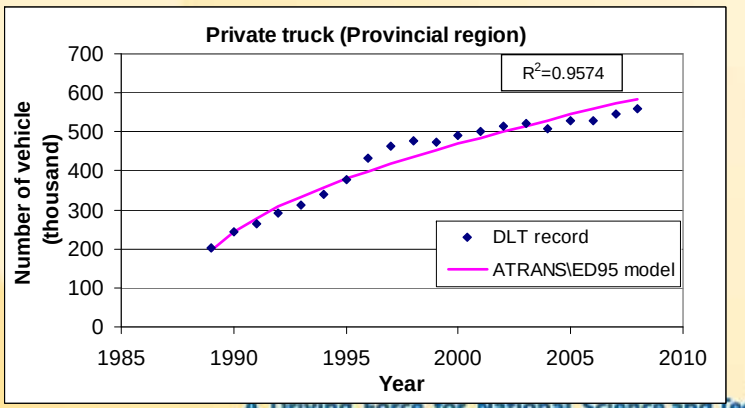












Percent share of fuel used in vehicle stocks

	Single liquid fuel engine				Dual-fuel engine				Dedicated gas	
	SI Engine			CI Engine	Bi-fuel SI LPG	Bi-fuel SI CNG	DDF LPG	DDF CNG	LPG dedic.	CNG dedic
	Gasoline	E10	E20							
PC01 private passenger car	78.16			20.38%	1.46%	0.00%	0.00%	0.00%	0.00%	0.00%
	42.86%	56.57%	0.57%							
PC02 pickup	5.25%			94.75%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	67.95%	32.05%	0.00%							
PC03 motor tri-cycle	42.26%			0.00%	17.84%	0.00%	0.00%	0.00%	37.48%	2.22%
	79.58%	20.42%	0.00%							
PC04 taxi	14.61%			0.00%	77.00%	7.62%	0.00%	0.00%	1.37%	0.00%
	42.86%	56.57%	0.57%							
PC05 commercial rent car	69.73%			26.92%	3.35%					0.00%
	42.86%	56.57%	0.57%							
PC06 motor cycle	100.00%			0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	65.57%	34.43%	0.00%							
Bus07 fixed route bus	1.24%			94.77%	2.39%	0.00%	0.00%	0.00%	0.00%	1.60%
	100.00%	0.00%	0.00%							
Bus08 non fixed route bus	0.39			99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Bus09 private bus	0.80%			99.20%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Truck10 non fixed route truck	0.00%			99.30%	0.00%	0.00%	0.22%	0.48%	0.00%	0.00%
	100.00%	0.00%	0.00%							
Truck11 private truck	0.39%			99.61%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00
	100.00%	0.00%	0.00%							

Small amount ~ 0%

Fuel Economy for Single Fuel Engine: Derivation from 1997 data

- ***Assumption***: The fuel economy is depended only on the vehicle (engine) size and the engine technology.
  a) So, the ***FE ratio*** (SI to SI, or CI to CI) between two vehicle types are constant during the consideration year.

$$FE. \propto \left\{ \begin{array}{c} \text{engine size,} \\ \text{engine technology} \end{array} \right\}$$

  b) And also the ***FE ratio*** between two engine technology (SI to CI) of each vehicle type are constant by the same manner.

NEPO & KMUTT 1997

km/litre	SI Engine			Diesel
	Gasoline	Gasohol E10	Gasohol E20**	
PC01	1	-	-	1.0763
PC02	1.0552	-	-	1.1597
PC03	1.0601	-	-	1.2116
PC04	0.9881	-	-	1.1294

EPPO 2008

	Gasoline	Gasohol E10	Gasohol E20**	Diesel
PC01	10.62*	11.30*	-	11.44*
PC02	10.00*	-	-	11.21*
PC03	-			
PC04	-	-	-	-

yr.1997 => yr.2008

km/litre	SI Engine			Diesel
	Gasoline	Gasohol E10	Gasohol E20**	
PC01	10.62*	11.30*	9.85	11.44*
PC02	10.00*	9.64**	9.28	11.21*
PC03	10.92**	10.52**	10.13	12.00**
PC04	10.58**	10.20**	9.82	11.63**
PC05	11.83**	11.40**	10.97	13.00**

Fuel Economy for Bi-fuel and Diesel Dual Fuel

Bi-fuel engine:

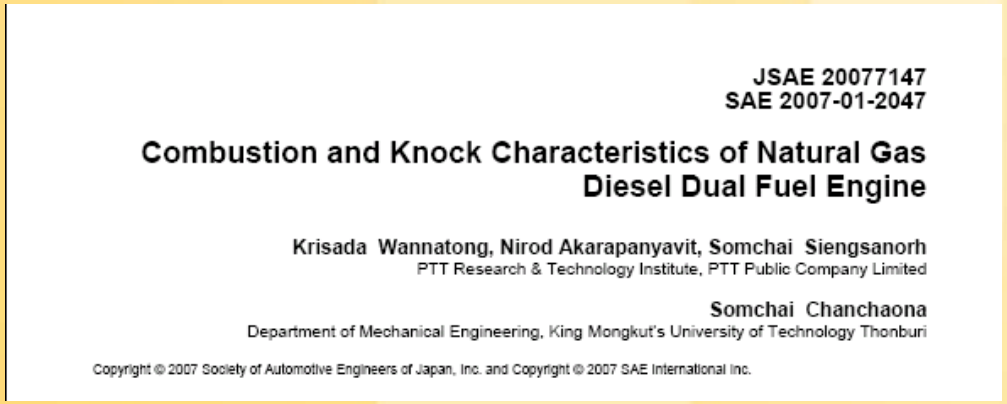
$$e.d. = FE_l \cdot DS_l + FE_g \cdot DS_g$$

Diesel Dual fuel:

$$e.d. = FE_{DDF.} \cdot \left(DS_l + DS_g \right)$$

**note DS : Device share by energy unit*

- The device share (DS.) and fuel economy (FE.) of the Diesel Dual Fuel are referred to **"Wannatong et al., SAE2007-01-2047"**



JSAE 20077147
SAE 2007-01-2047

Combustion and Knock Characteristics of Natural Gas Diesel Dual Fuel Engine

Krisada Wannatong, Nirod Akarapanyavit, Somchai Siengsanorh
PTT Research & Technology Institute, PTT Public Company Limited

Somchai Chanchaona
Department of Mechanical Engineering, King Mongkut's University of Technology Thonburi

Basic of energy demand calculation

$$\underset{\text{(energy demand)}}{ED.} = \underset{\text{(number of vehicle)}}{NV.} \times \underset{\text{(vehicle kilometer of travel)}}{VKT.} \times \underset{\text{(fuel economy)}}{FE.}$$

when :

$$ED = \sum_{\substack{i,\ \text{vehicle type} \\ j,\ \text{region}}} ED_{i,j}$$

$$ED_i = \sum_{k,\ \text{fuel used}} ED_k$$

- There are MANY fuel choices and MANY engine technology to calculate fuel consumption
- Issues with Bi- and Dual-fuel
- Need certain assumption in the calculation

Bi-fuel engine:

$$e.d. = FE_l \cdot DS_l + FE_g \cdot DS_g$$

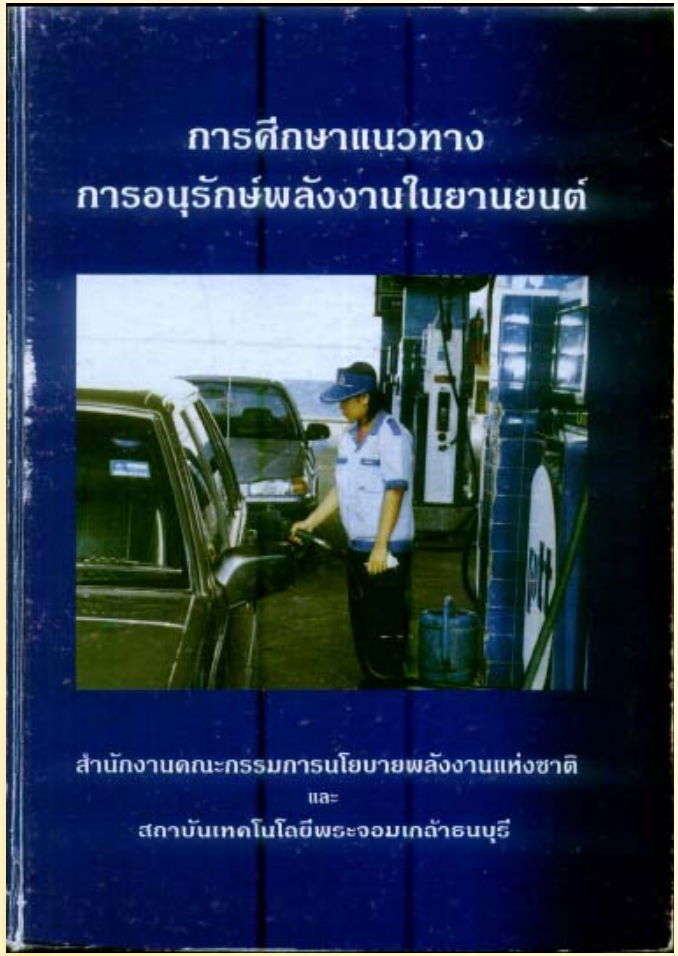
Diesel Dual fuel:

$$e.d. = FE_{DDF.} \cdot \left(DS_l + DS_g\right)$$

**note DS : Device share by energy unit*

Fuel economy and Vehicle Kilometer of Travel

EPPO report, 2008



NEPO & KMUTT, 1997

Fuel economy (BKK)

km/litre	Single fuel engine				Dual fuel engine				Dedicated engine	
	SI Engine			Diesel	Bi-fuel SI LPG	Bi-fuel SI CNG	Diesel DDF LPG	Diesel DDF CNG	LPG dedic.	CNG dedic
	Gasoline	Gasohol E10	Gasohol E20**							
PC01	10.62*	11.30*	9.85	11.44*					9.87*	10.85*
PC02	10.00*	9.64**	9.28	11.21*					11.57*	11.33*
PC03	10.92**	10.52**	10.13	12.00**					9.71*	9.29*
PC04	10.58**	10.20**	9.82	11.63**					9.83**	10.81**
PC05	11.83**	11.40**	10.97	13.00**					10.99**	12.08**
PC06	32.77*	29.24*	-	-					-	-
Bus01	2.18**	2.10**	2.03	2.40*					2.03**	1.86*
Bus02	2.09**	2.01**	1.94	2.30**					1.94**	2.13**
Bus03	2.10**	2.02**	1.95	2.31**					1.95**	2.14**
Truck01	2.57**	2.48**	2.38	2.83*					2.39**	2.63**
Truck02	2.22**	2.14**	2.06	2.44**					2.07**	2.27**

Bi-fuel engine:

$$e.d. = FE_l \cdot DS_l + FE_g \cdot DS_g$$

Diesel Dual fuel:

$$e.d. = FE_{DDF.} \cdot \left(DS_l + DS_g\right)$$

**note* *DS : Device share by energy unit*

*EPPO report, 2008

**Extrapolated from NEPO & KMUTT, 1997 using engine size/technology assumptions

Road distance & Number of vehicle

Year	Total road distance (Rural)	Total number of vehicles	
		Bangkok	Rural
1996	53,768	3,549,082	12,544,814
1997	55,321	3,872,327	13,793,913
1998	57,233	4,016,594	14,843,918
1999	59,306	4,162,846	15,933,690
• • •	• • •		
2004	63,287	4,288,468	16,336,251
2005	63,062	4,899,969	17,671,093
2006	63,773	5,557,111	19,250,186
2007	64,745	5,715,078	19,903,369

Simplest model to estimate VKT!!!

over time

$$\frac{Rd_2}{Rd_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

km supply $\propto$ km demand

sum over VKT x NV of each vehicle type

Assume road expansion mostly from provincial region (data obtained from Department of Highways)

Thailand transport portal ***(Rural)***

http://vigportal.mot.go.th/portal/site/PortalMOT/stat/index6URL/

Vehicle Kilometer of Travel

Assume little road expansion

$$\frac{Rd_2}{Rd_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

$$\frac{Rd_2}{Rd_1}(\cong 1) = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

$$\frac{VKT_2}{VKT_1} = \frac{\sum NV_1}{\sum NV_2}$$

$$= 0.6956$$

$$= 69.56\%$$

Bangkok

$$\frac{Rd_2}{Rd_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$

$$\frac{VKT_2}{VKT_1} = \frac{Rd_2}{Rd_1} \cdot \frac{\sum NV_1}{\sum NV_2}$$

$$= 0.8201$$

$$= 82.01\%$$

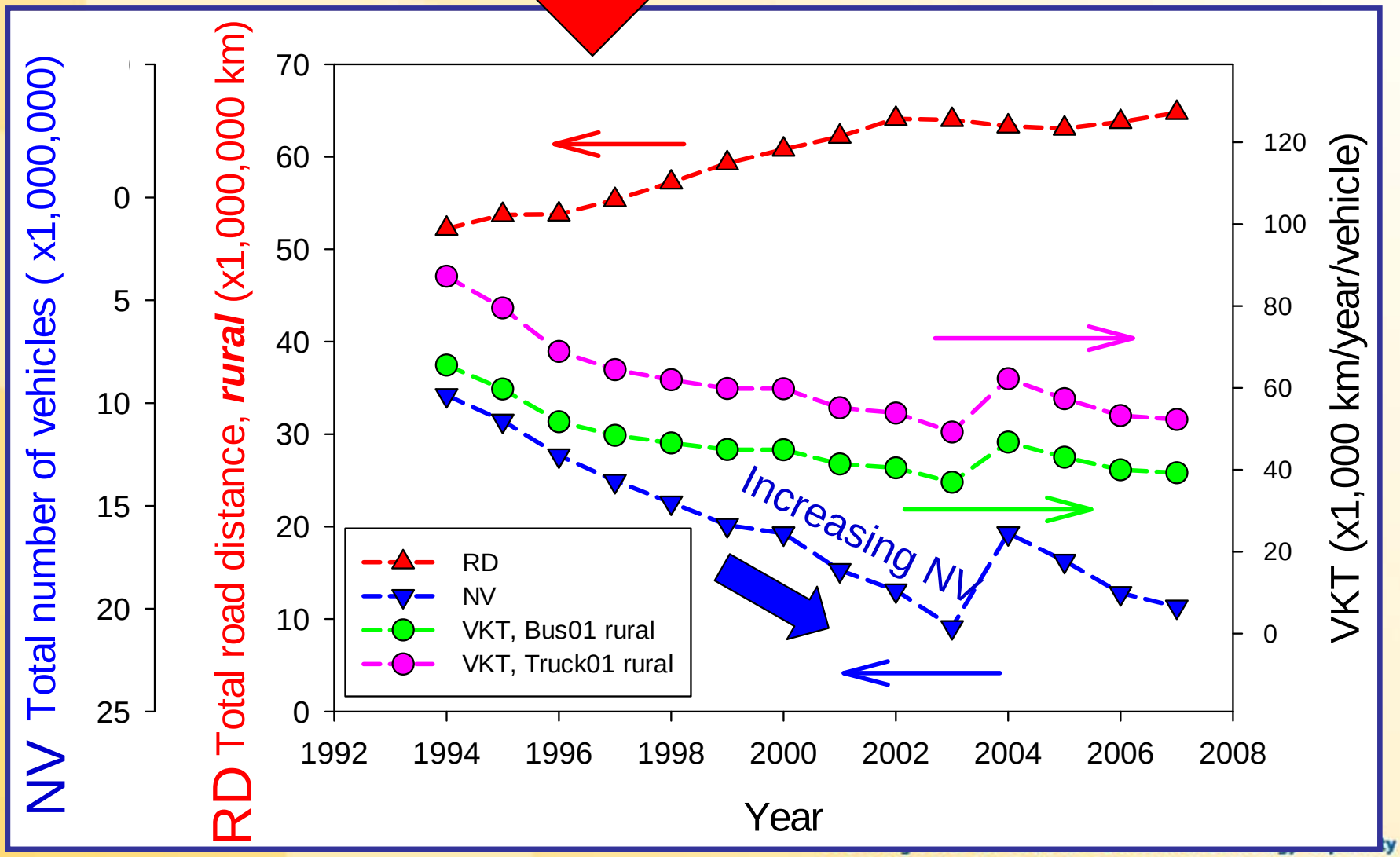
Provincial area

Yr 1 is 1997 (NEPO & KMUTT data)
Yr 2 is 2008 (EPPO data)

Survey of VKT only available in this two years

Road distance & Number of vehicle

$$\frac{Rd_2}{Rd_1} = \frac{VKT_2}{VKT_1} \cdot \frac{\sum NV_2}{\sum NV_1}$$



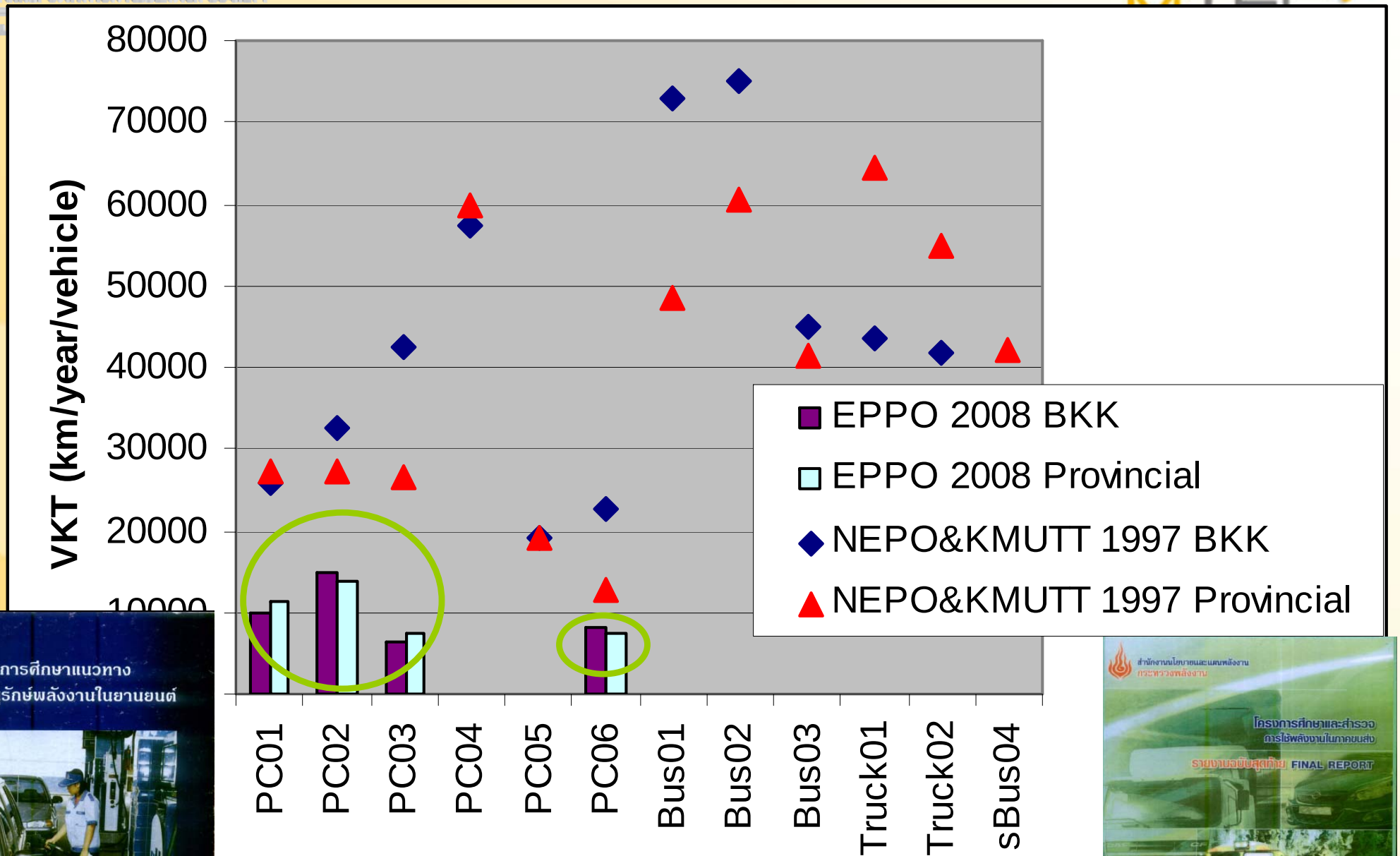
Vehicle Kilometer of Travel

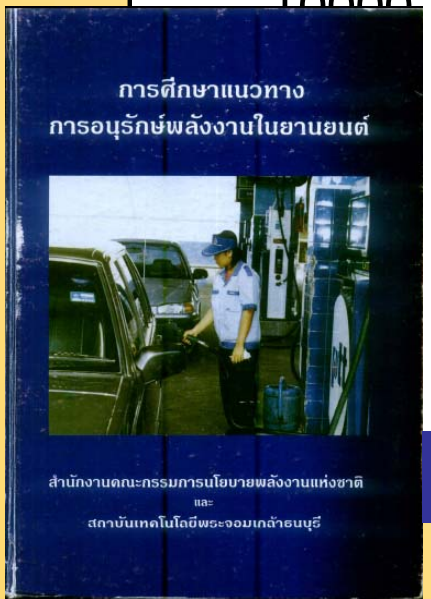
	Bangkok	Province
PC01 passenger car	9,887*	11,264*
PC02 pickup	15,008*	13,746*
PC03 Motor tri-cycle	6,500*	7,475*
PC04 Taxi	39,982**	49,208**
PC05 Commercial rent car	13,407**	15,808**
PC06 Motor cycle	8,097*	7,414*
Bus01 Fixed route bus	50,746**	39,687**
Bus02 Non fixed route bus	52,168**	49,559**
Bus03 Private bus	31,301**	34,018**
sBus04 Small bus	-	34,433**
Truck01 Non fixed route truck	30,211**	52,845**
Truck02 Fixed route truck	29,128**	44,924**

*EPPO report, 2008

**Estimate in this work by referring to EPPO & KMUTT, 1997

Vehicle Kilometer of Travel



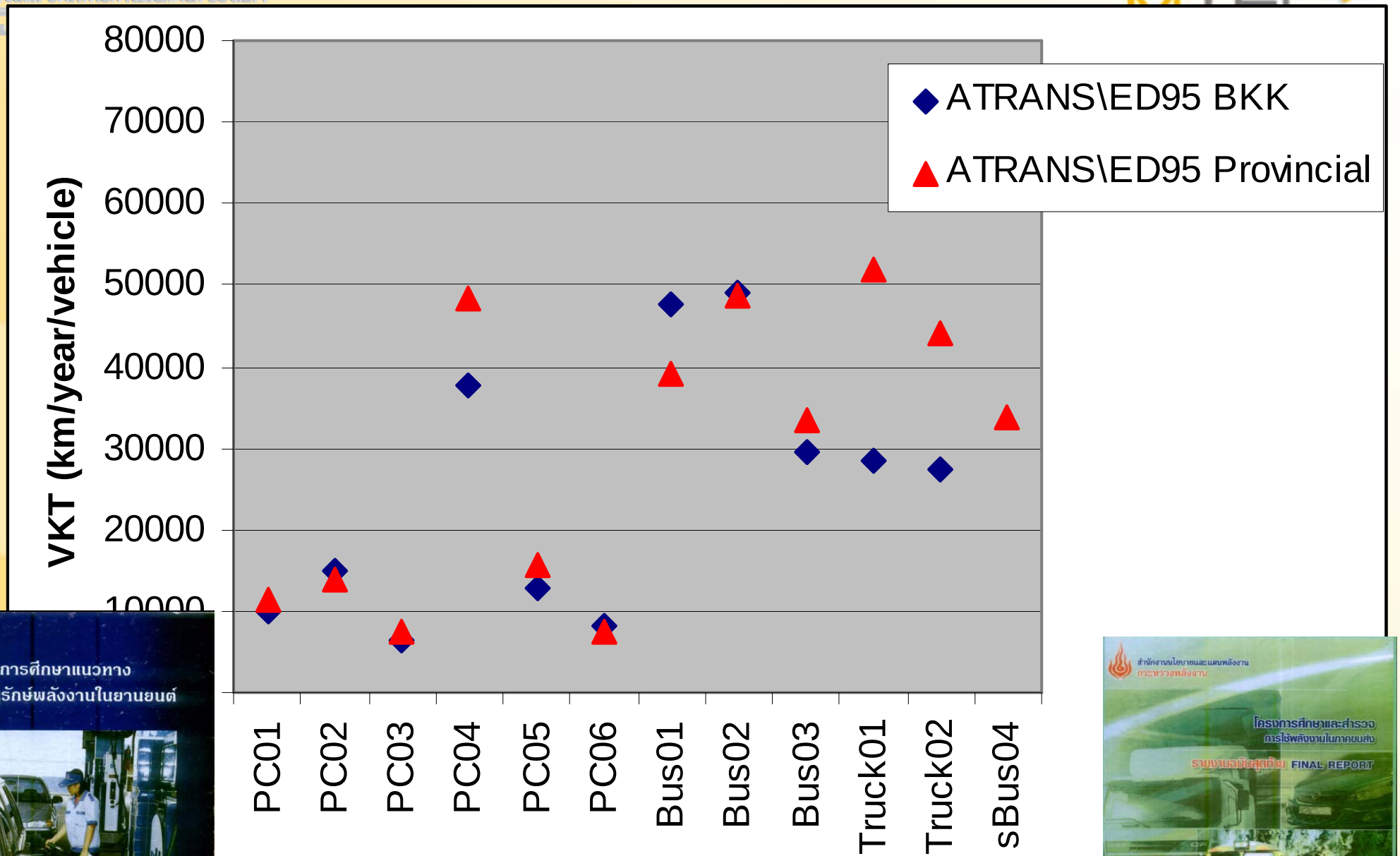


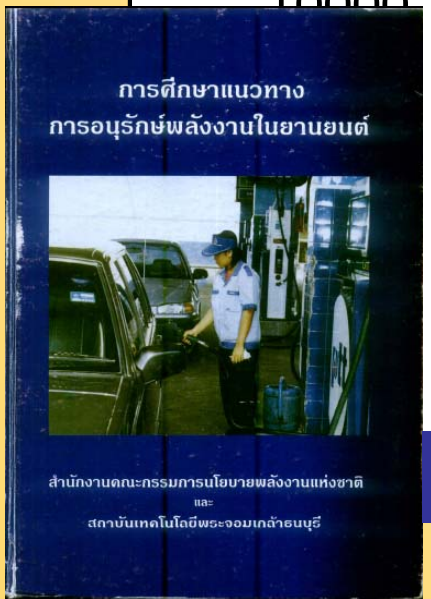
NEPO & KMUTT 1997

EPPO 2008

A Driving Force for National Scie

Vehicle Kilometer of Travel





NEPO & KMUTT 1997

EPPO 2008

Validation with historic records

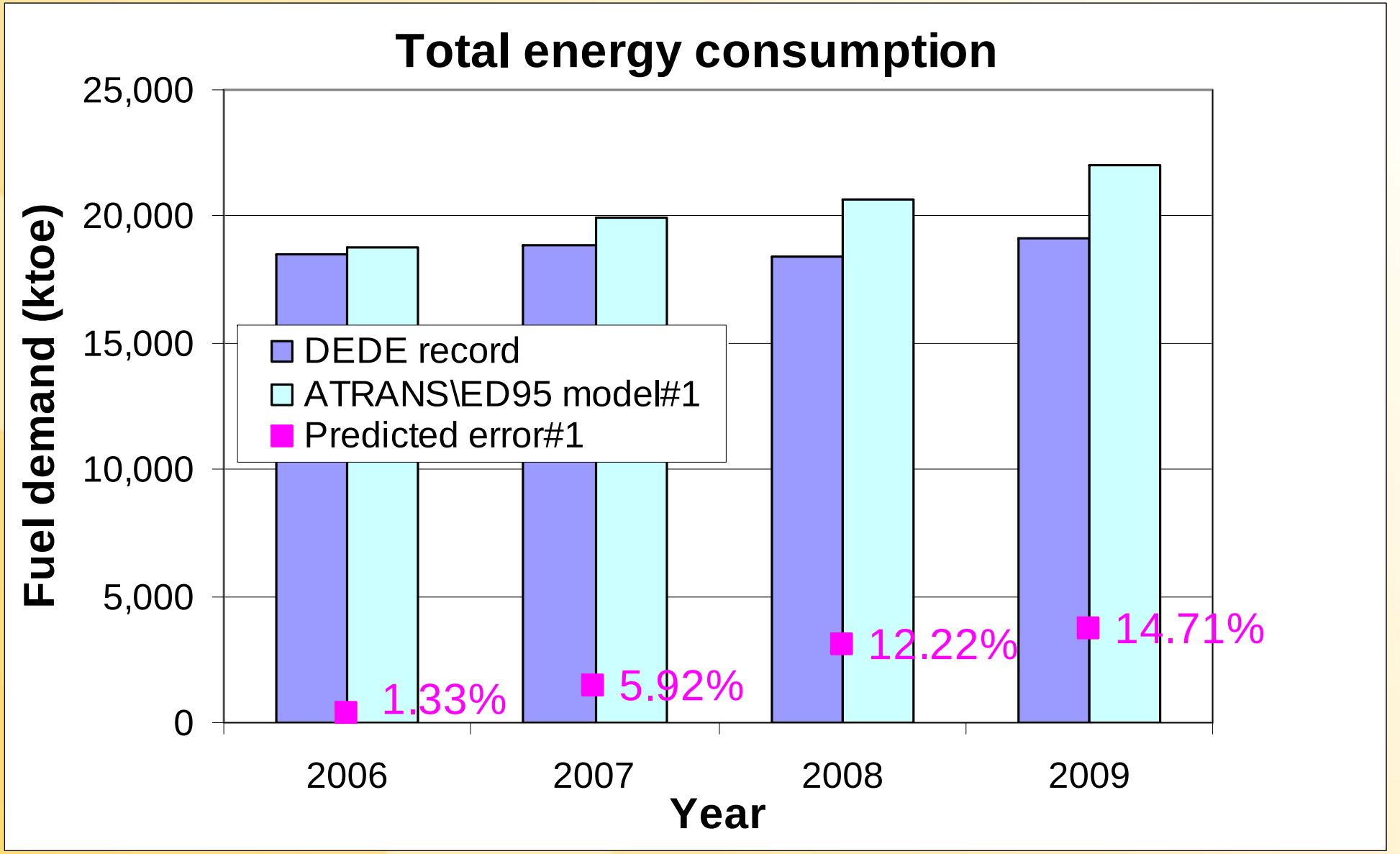
Reports from
Department of Alternative
Energy Development and Efficiency (DEDE)

Need correction factors with fuel price

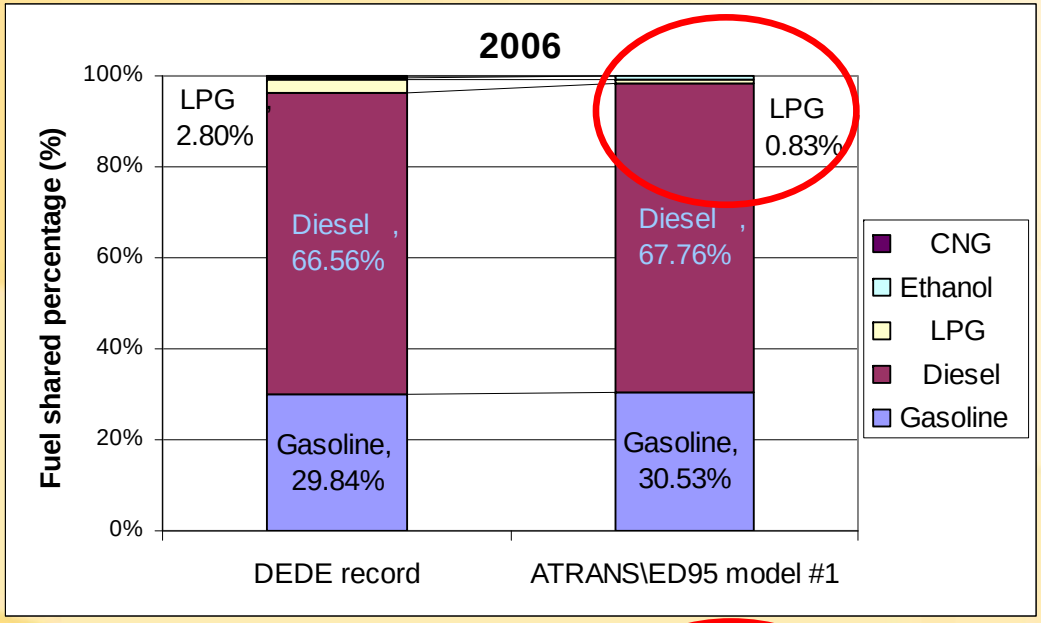
Thailand energy situation
2006, 2007, 2008

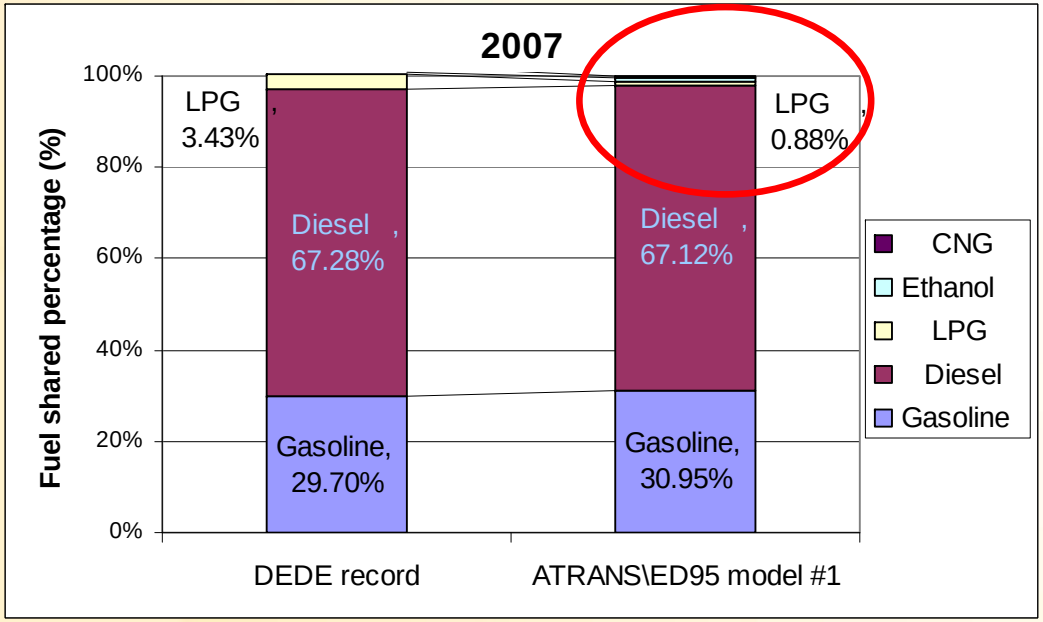
Thailand energy statistics
2009 (Preliminary report)

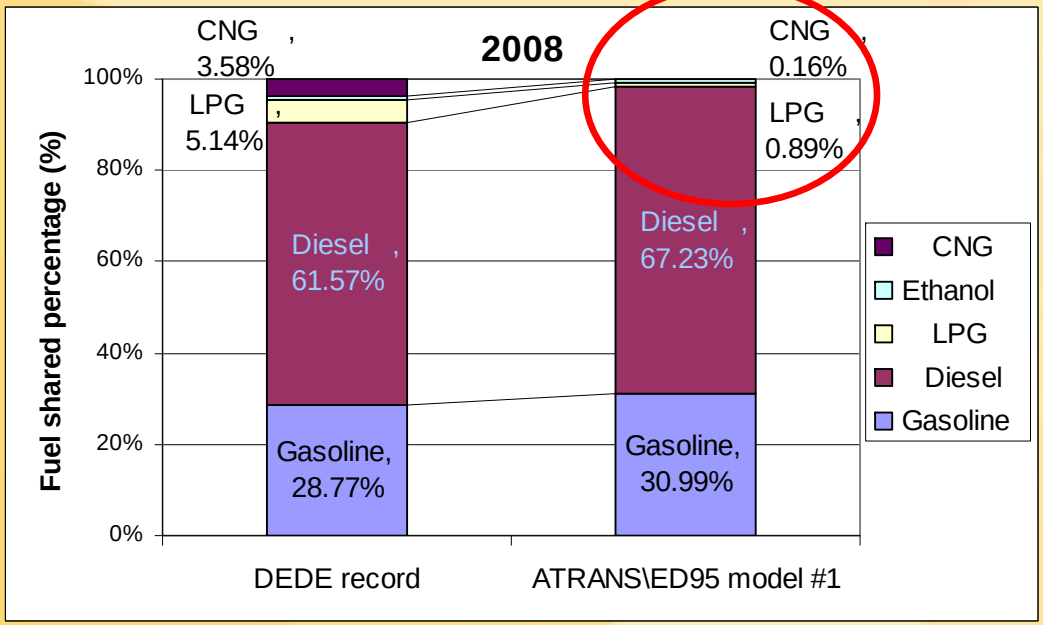
Old results from interim meeting

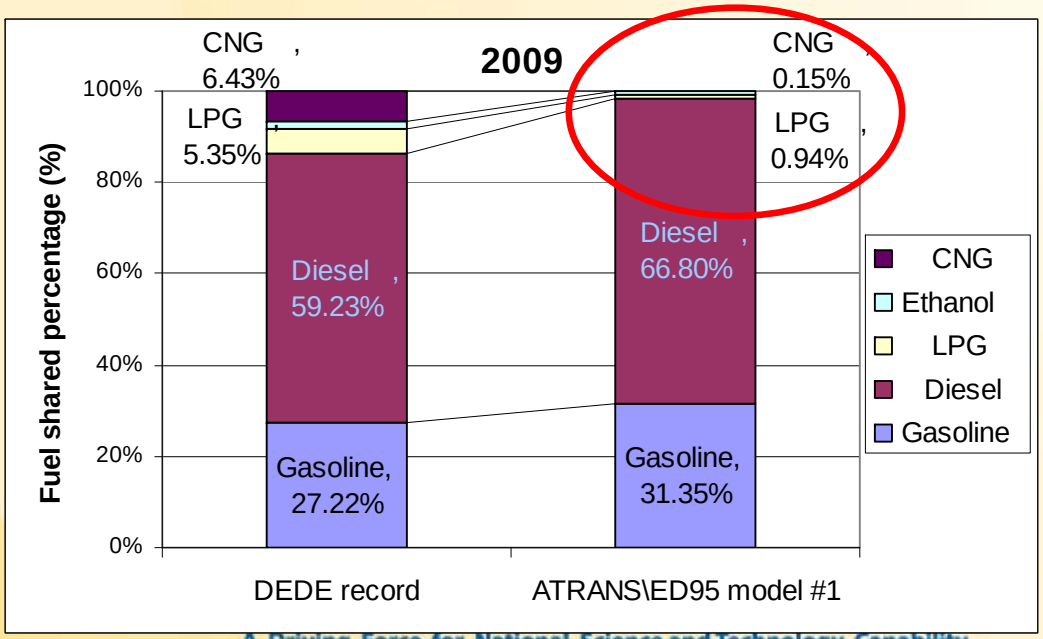


Old BAU from 2nd Advisory meeting









Correction factors (CF)

- Influencing parameters from real situation
  - Crude oil price (i.e., energy crisis)
  - Currency exchange rate (i.e., economic situation)
  - Other (i.e., tax, political subsidize)

→ Distributed fuel price (ex-refinery)

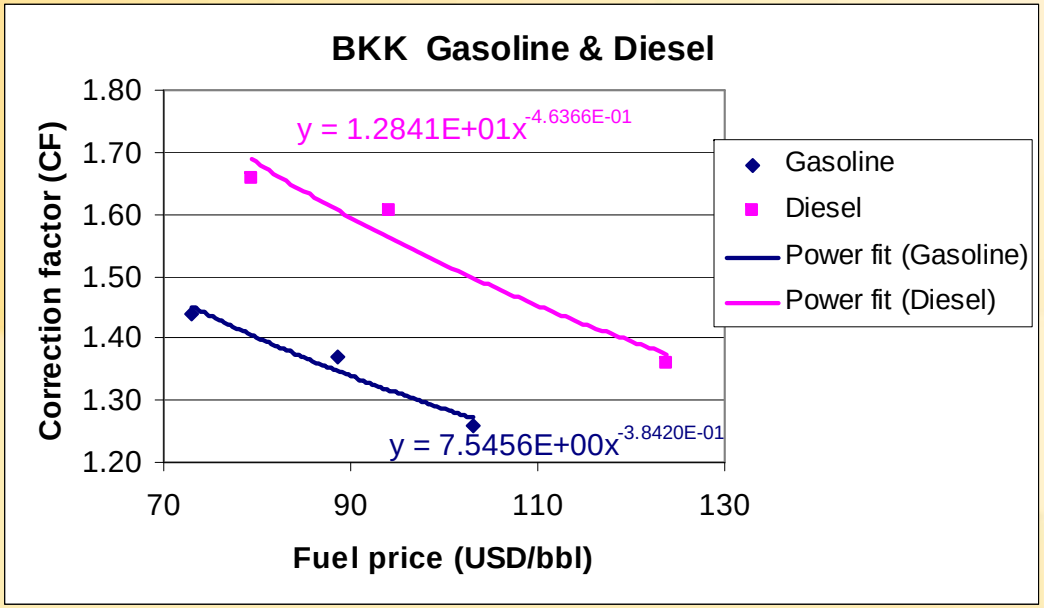
- Affected variables in model
  - Fuel share evolution
  - FE
  - VKT

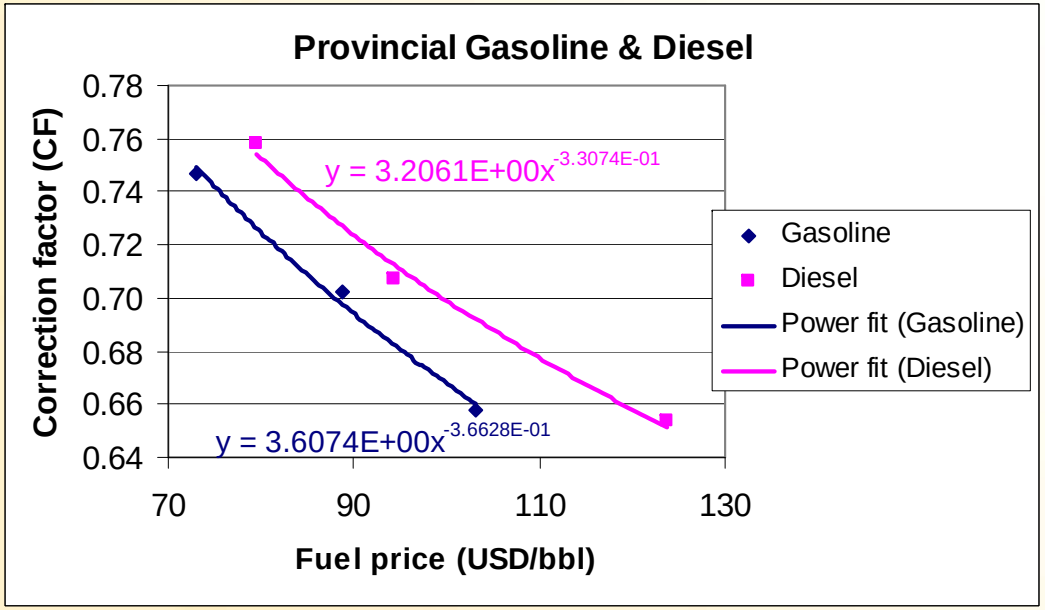
→ Mileage correction factor

$$= \frac{Historic\ value}{Predicted\ value}$$

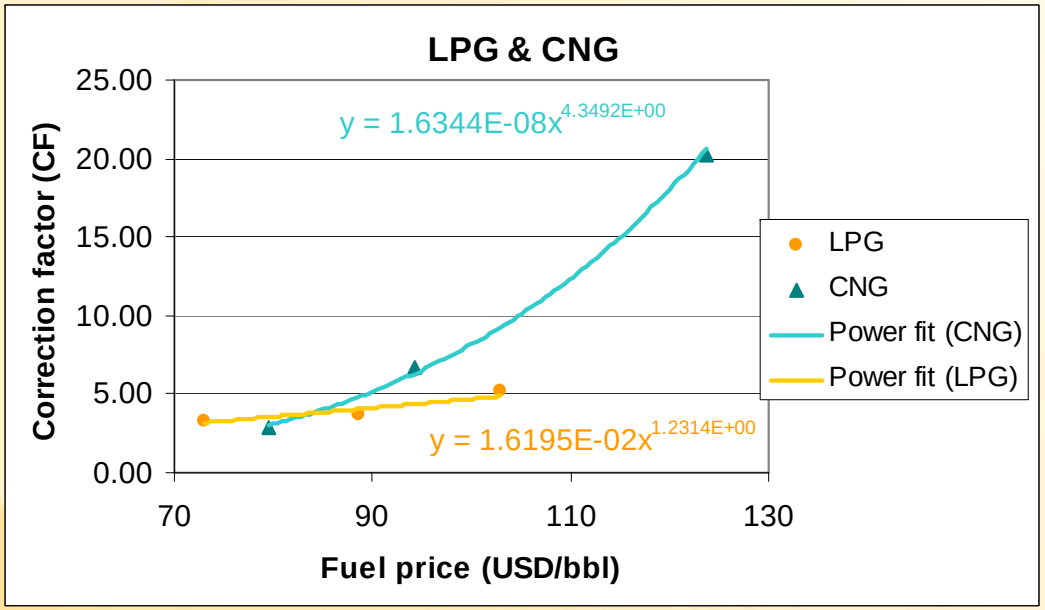
- Demand vs supply depending on fuel price
  - Gasoline
  - Diesel
  - LPG
  - CNG

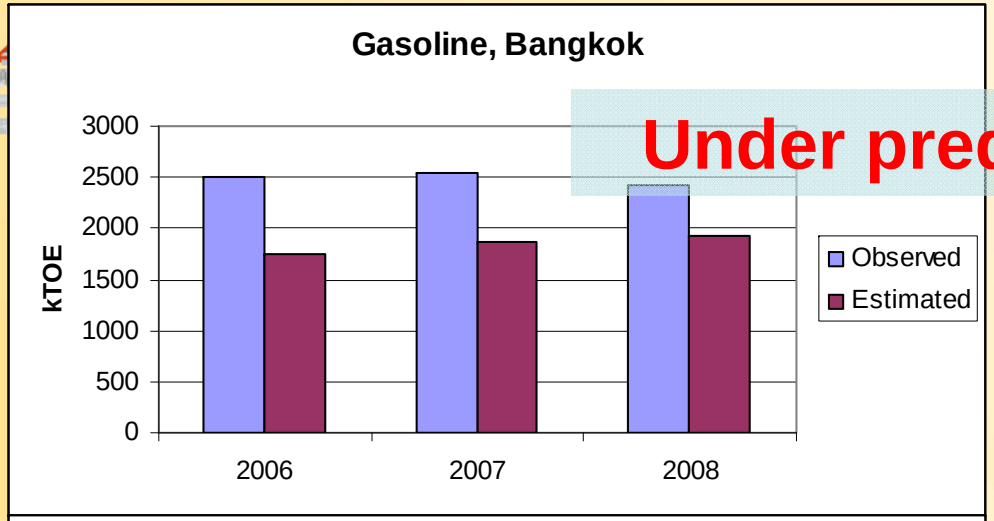
Correction factors (CF)

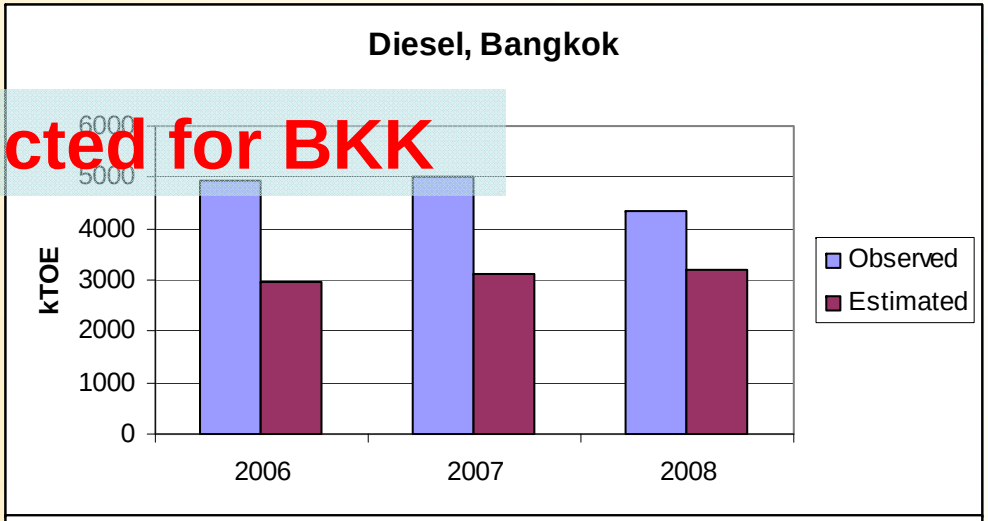




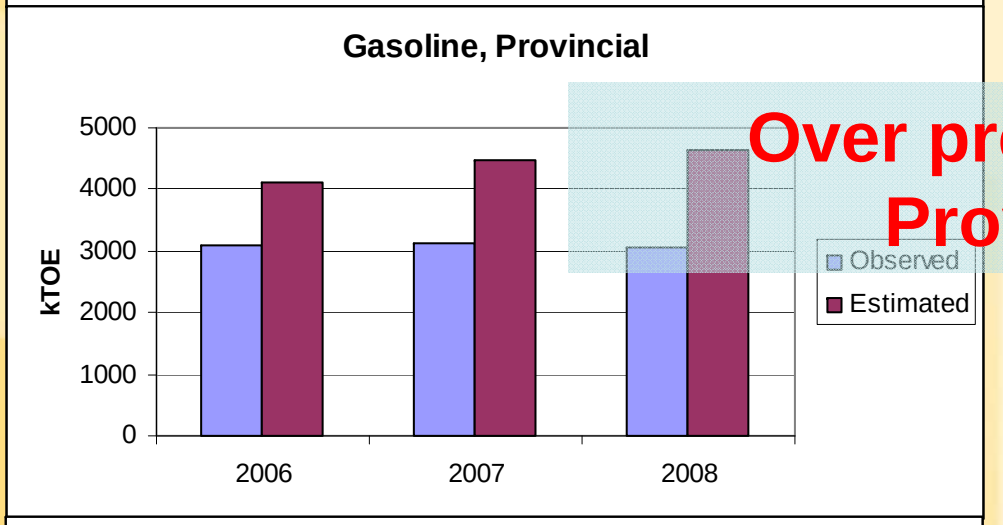
Keep in mind that this CF will not be applied on the vehicle types whose driving habit does not affect on fuel price such as the fixed route bus or Taxi.

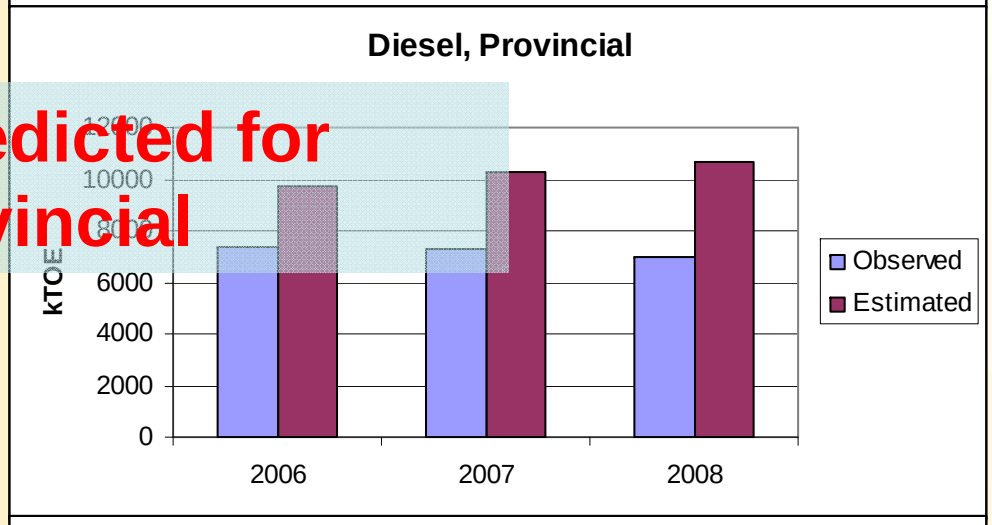




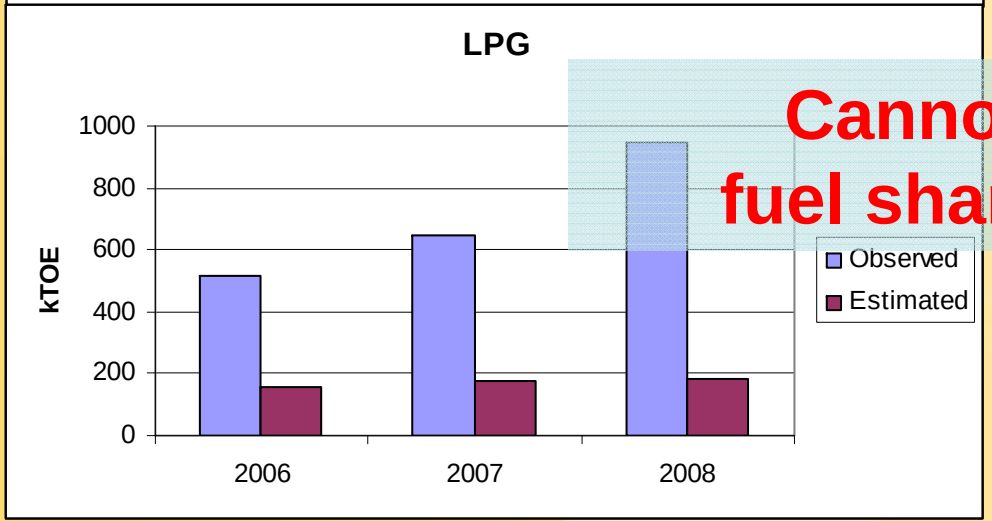


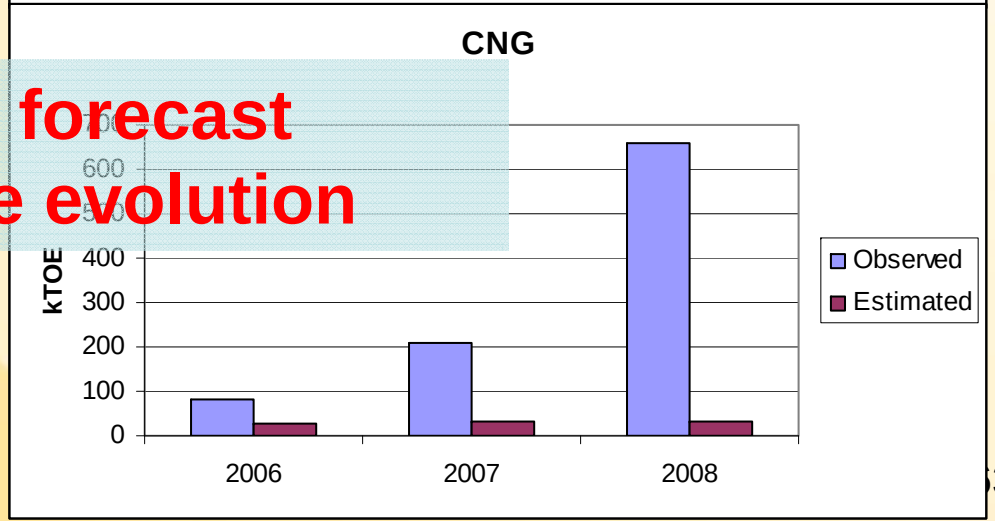
Under predicted for BKK





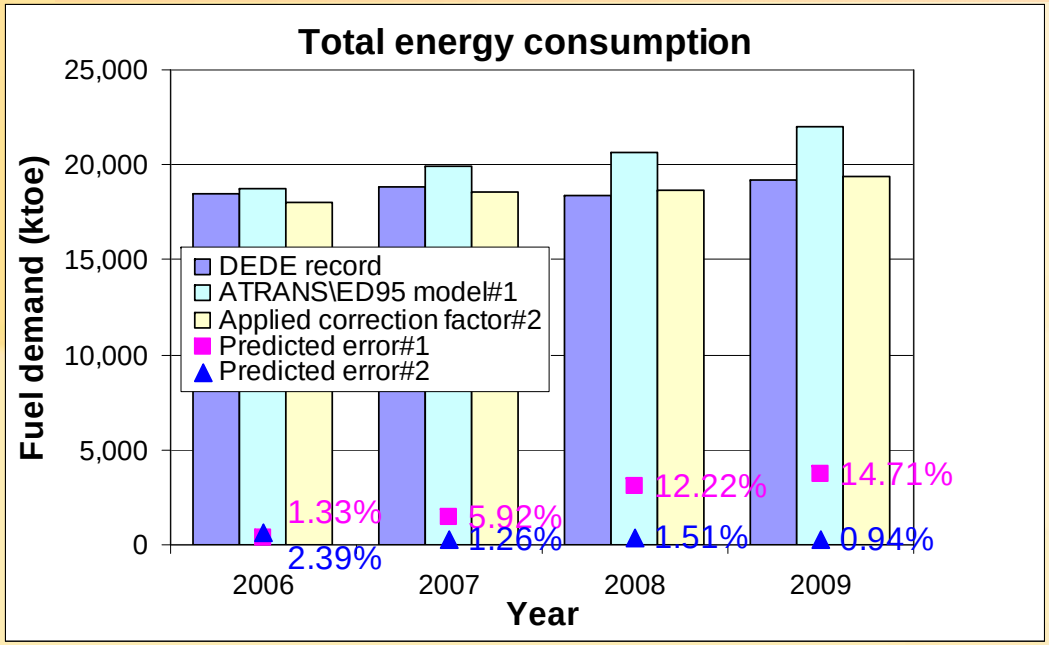
Over predicted for Provincial



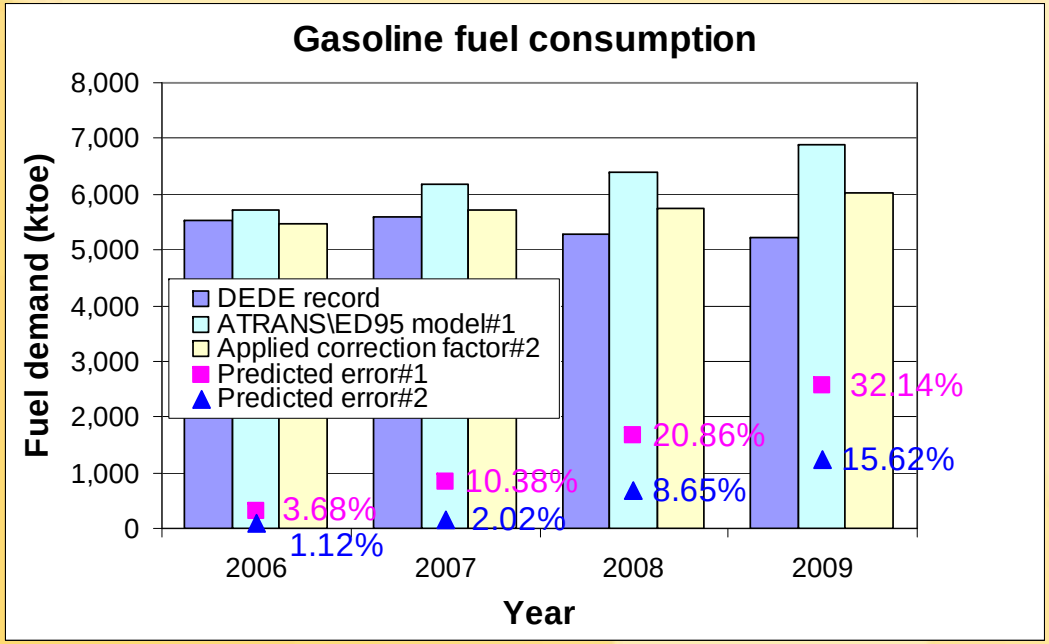


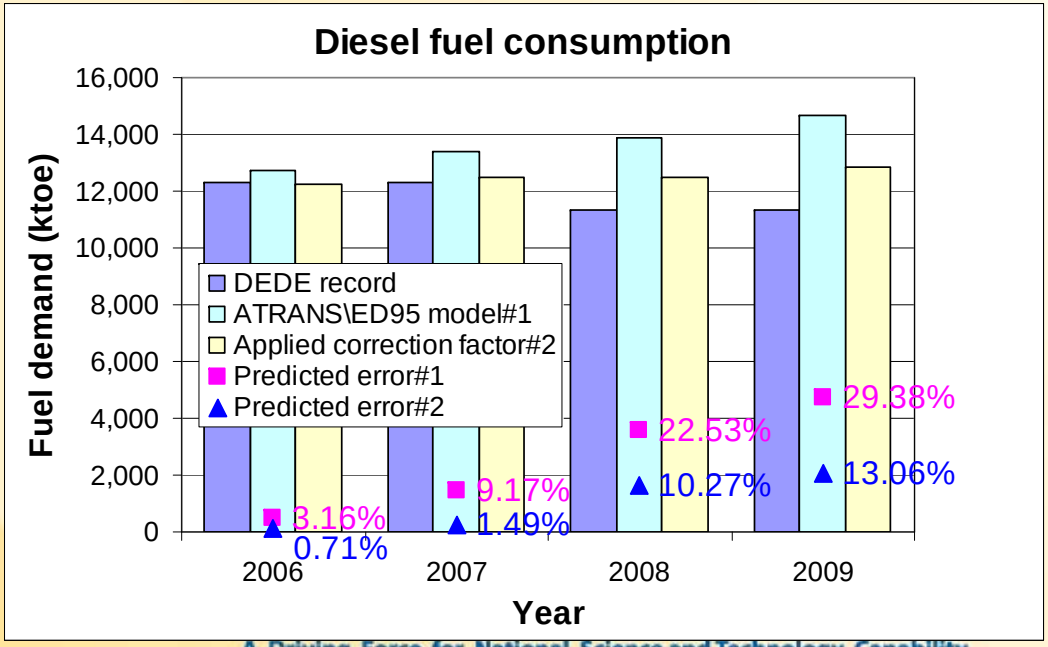
Cannot forecast fuel share evolution

Model Validation

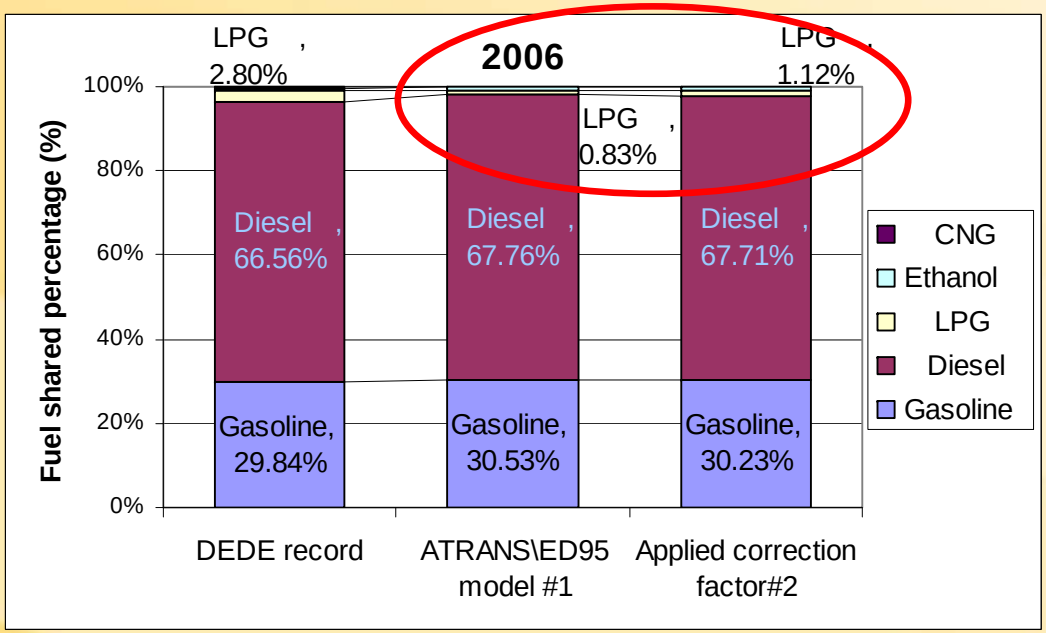


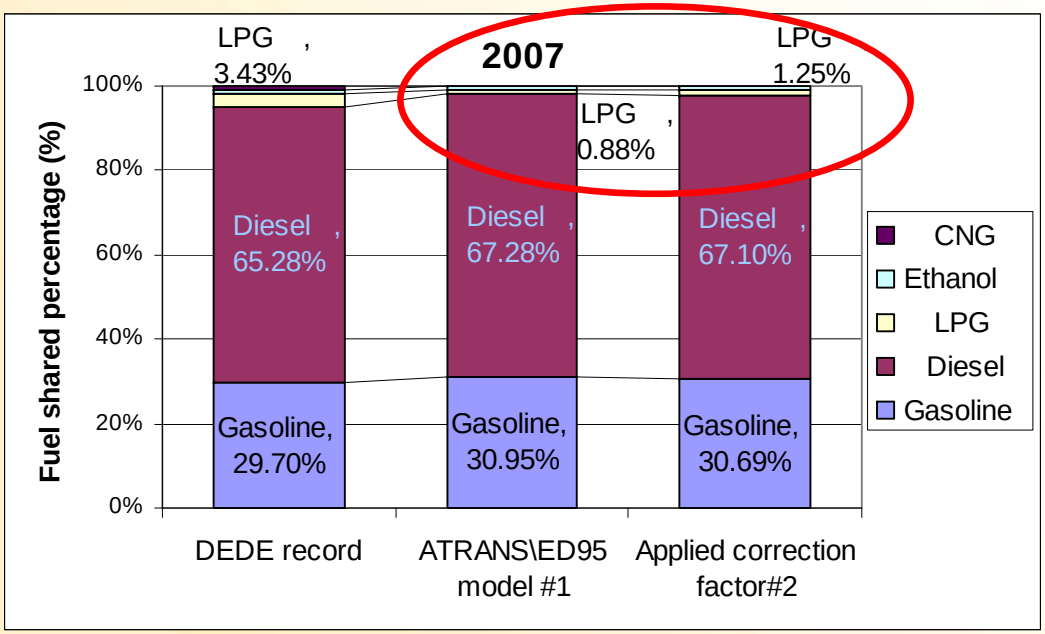
- Better agreement on total energy demand
- Absolute value for gasoline and demands still over predicted due to CNG/LPG
- LEAP cannot take into account of fuel change in existing vehicles like in the case of CNG/LPG conversion kit installation (only apply to new vehicle if fuel switching needs to be accounted for)

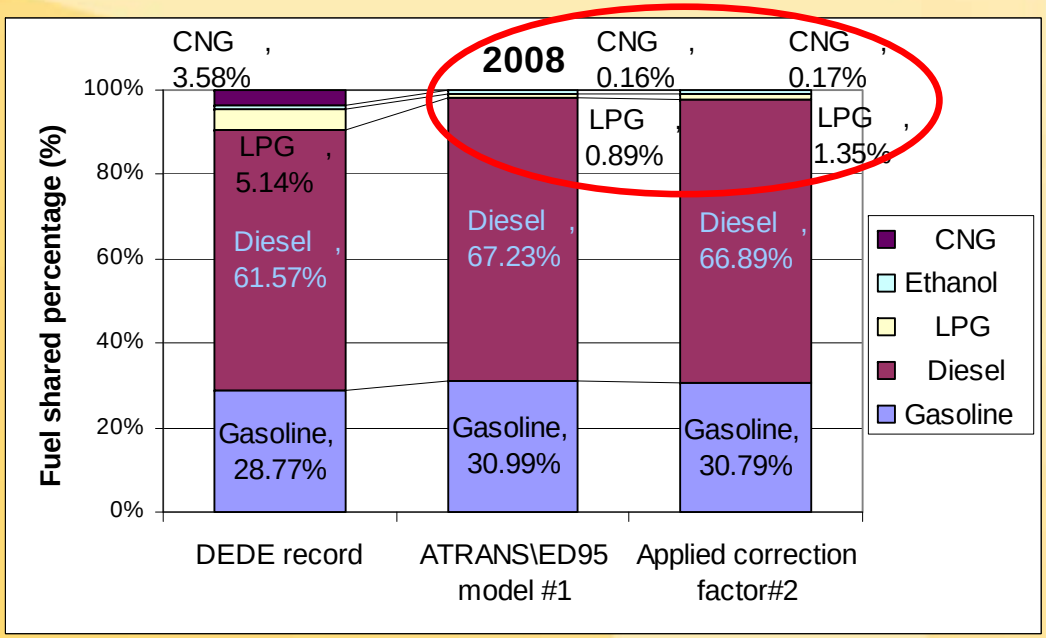


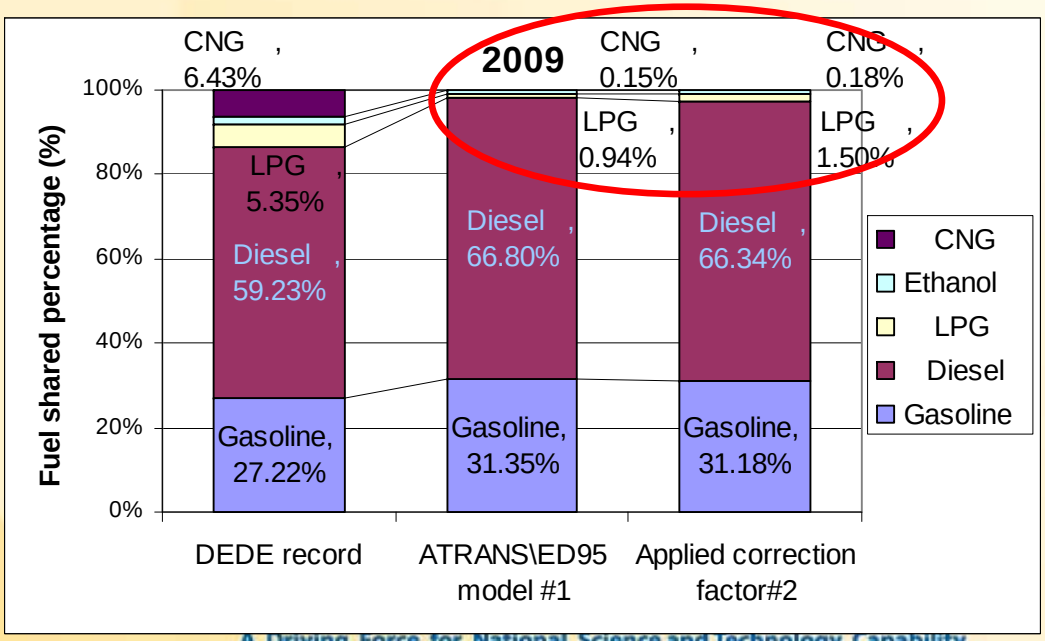


Model Validation in %

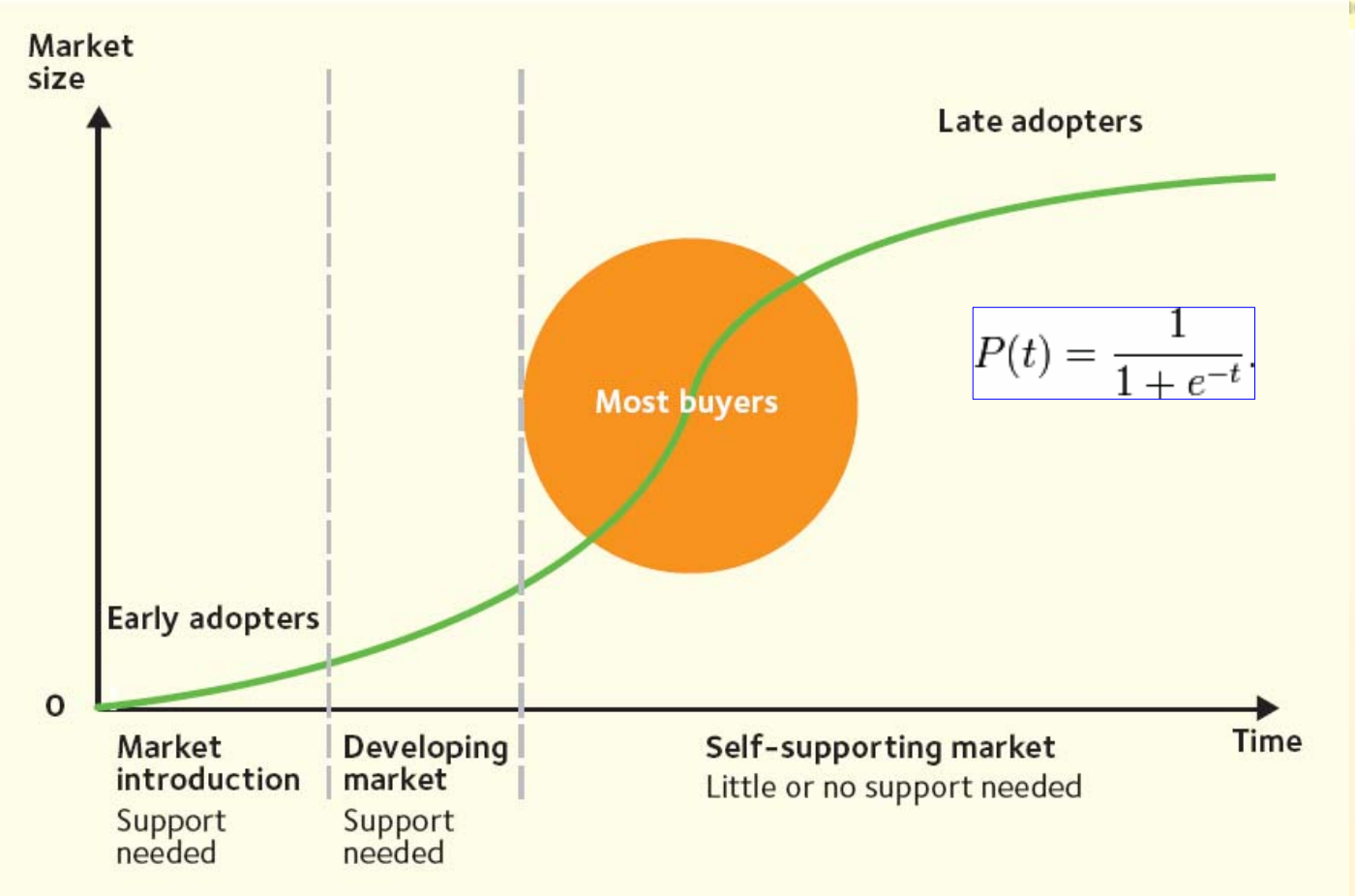








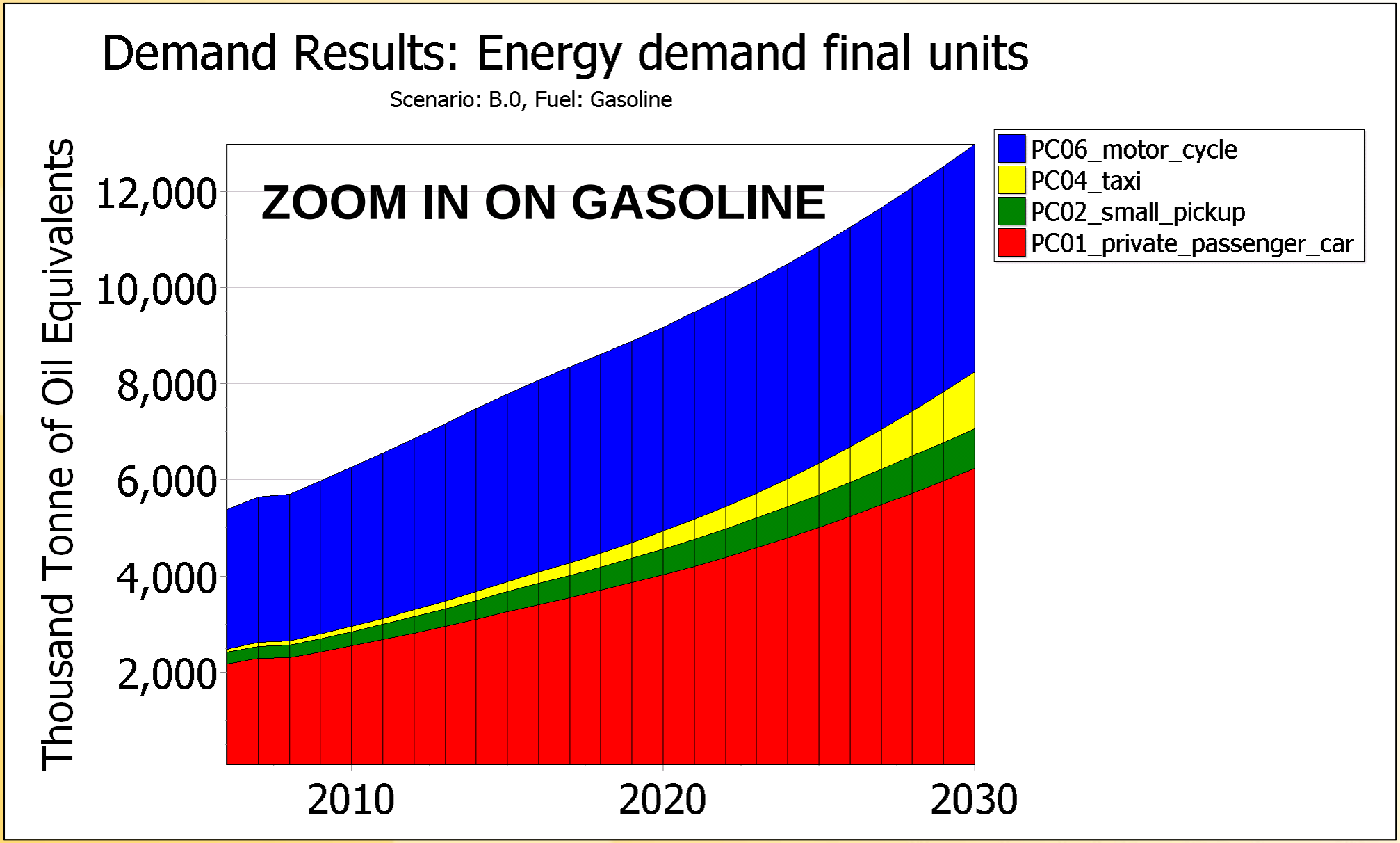
Market penetration of new technology



- Relationship between time and market penetration of new technology.
  - Market introduction → Developing market → Self-supported market

- Assume S-curve for all scenario analysis with a 10 years span

Gasoline fuel consumption by vehicle type

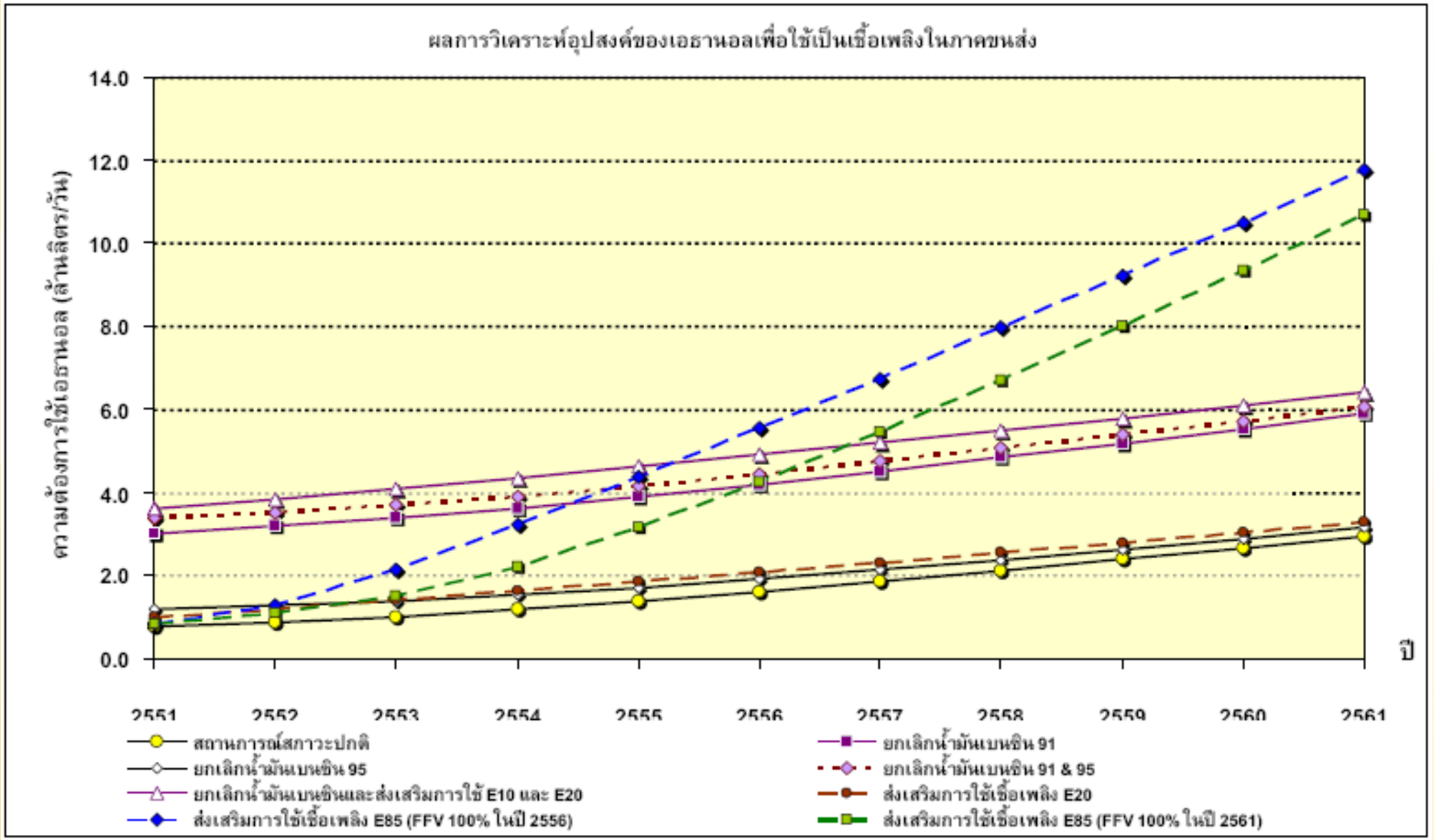


ตารางที่ 25 ปริมาณและมูลค่าการนำเข้าก๊าซธรรมชาติจำแนกตามแหล่งนำเข้า

TABLE 25 VOLUME AND VALUE OF NATURAL GAS IMPORTED BY SOURCE

แหล่งนำเข้า	2549 2006		2550 2007		2551 2008		2552[P] 2009[P]		SOURCE
	ปริมาณ ล้านลูกบาศก์ฟุต VOLUME MMscf	มูลค่า ล้านบาท VALUE Million Baht	ปริมาณ ล้านลูกบาศก์ฟุต VOLUME MMscf	มูลค่า ล้านบาท VALUE Million Baht	ปริมาณ ล้านลูกบาศก์ฟุต VOLUME MMscf	มูลค่า ล้านบาท VALUE Million Baht	ปริมาณ ล้านลูกบาศก์ฟุต VOLUME MMscf	มูลค่า ล้านบาท VALUE Million Baht	
พม่า									MYANMAR
ยาดานา	196,506	34,031	204,027	34,193	200,570	43,466	197,105	41,176	YADANA
เยตากุน	148,786	35,855	156,958	36,196	135,660	40,998	140,458	41,157	YETAKUN
รวม	345,292	69,886	360,985	70,389	336,230	84,464	337,563	82,333	TOTAL

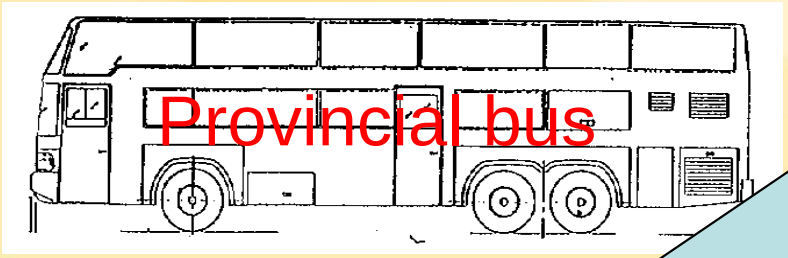
ที่มา : บริษัท ปตท. จำกัด (มหาชน) Source : PTT.



รูปที่ 5-27 สรุปปริมาณความต้องการใช้เชื้อเพลิงเอธานอลในสถานการณ์จำลองต่างๆ

Scenario development

- **BAU.** NGV bus (BKK+Provincial)[1]
  & apply Gasohol on SI vehicle[2]



Increasing measure to repl GV bus with ED95 bus

- **B.1** Fixed route bu 20 (BKK)
- **B.2.1** Fixed r s @2010 (BKK)
- **B.2.2** Fix te bus @2010 (BKK)
  2020 (Provincial)

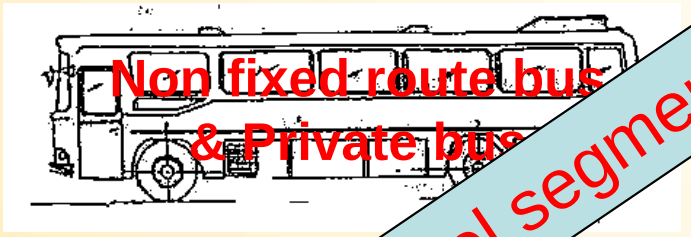
Substitute the NGV bus

[1]cabinet resolution on 27 May 2008
[2]E-policy report (E85 promotion plan)

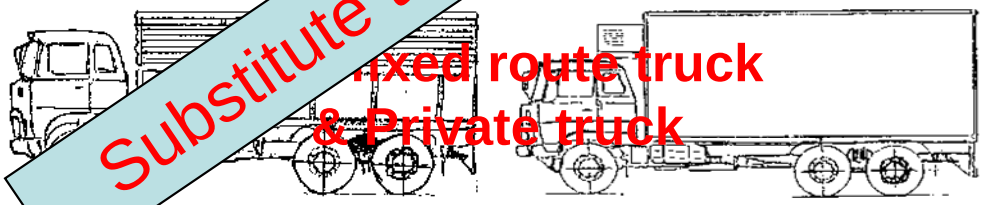
Expand to other diesel vehicles

B.2.2 + … (@2020)

- **C.1** Non fixed route bus (BKK)
- **C.2** Private bus (BKK)

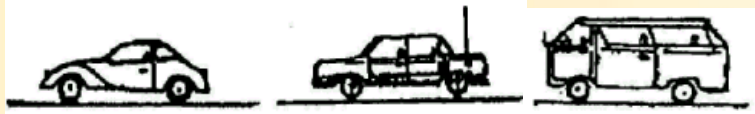


- **C.3** Non fixed ro ck (BKK)
- **C.4** Private BKK)

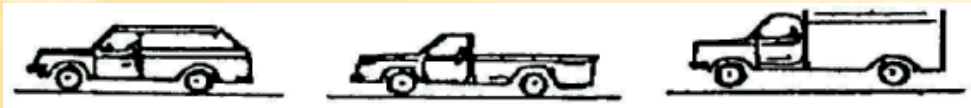


Substitute the Diesel segment

- **C.5** Passenger car (BKK)



- **C.6** Pickup & Van (BKK)



Conclusions

- Impact of ED95
  - Advantage
    - ✓ Replace fossil diesel import by indigenous ethanol fuel
    - ✓ Retain use of high efficiency compression-ignition (CI) engine but with ethanol fuel
    - ✓ Income distribution to Thai agriculture sector for ethanol production
    - ✓ Less capital intensive infrastructure & easier liquid ethanol fuel handle (compared to CNG)
  - Disadvantage
    - ✓ Availability of ED95 technology (fuel & engine)
    - ✓ Need modification to existing diesel engine to be compatible with ED95 fuel
  - Unknown?
    - ✓ Future oil price

Recommendation