Inventory and Mitigation Measures for Waste Sector in Thailand

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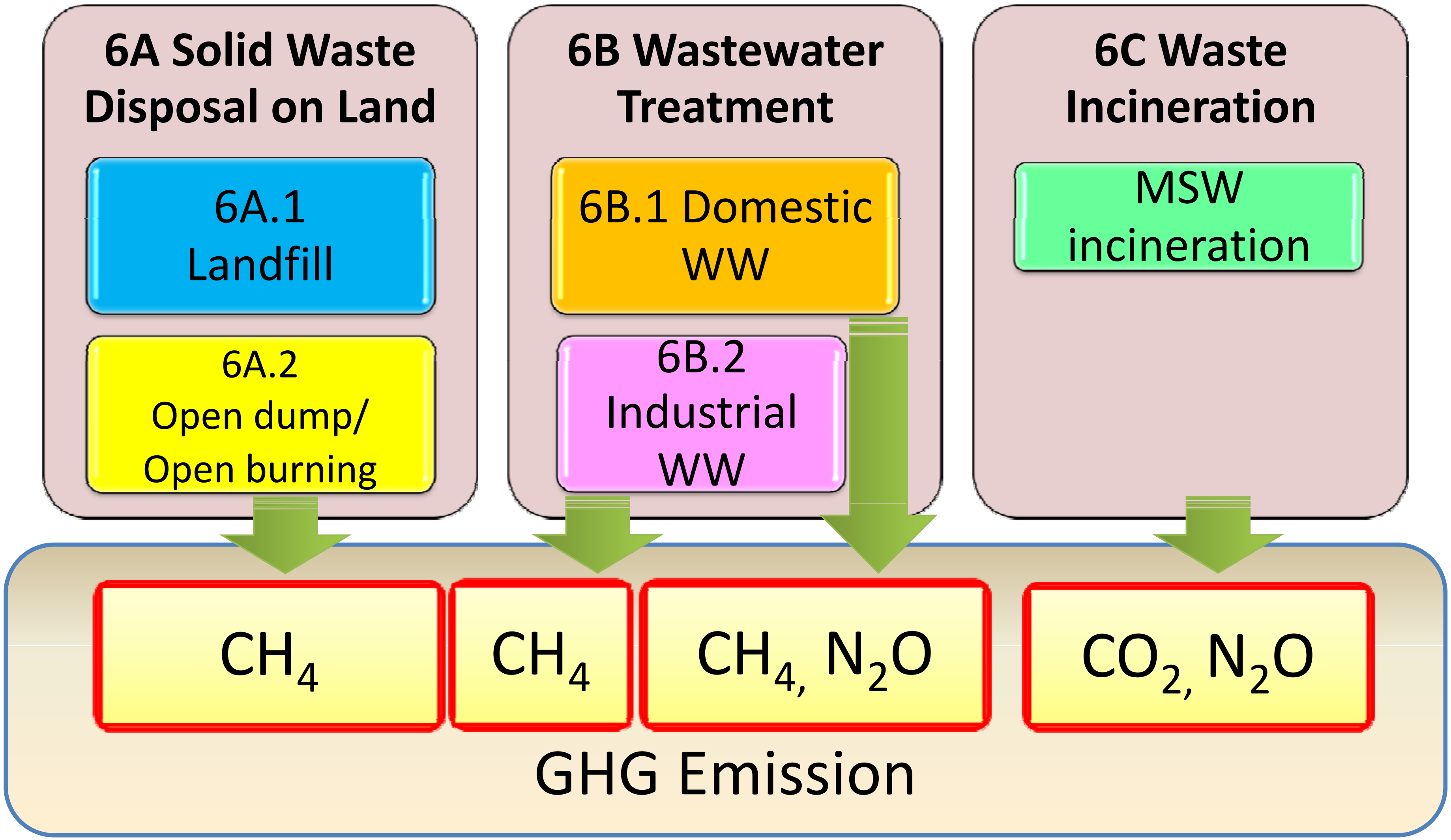
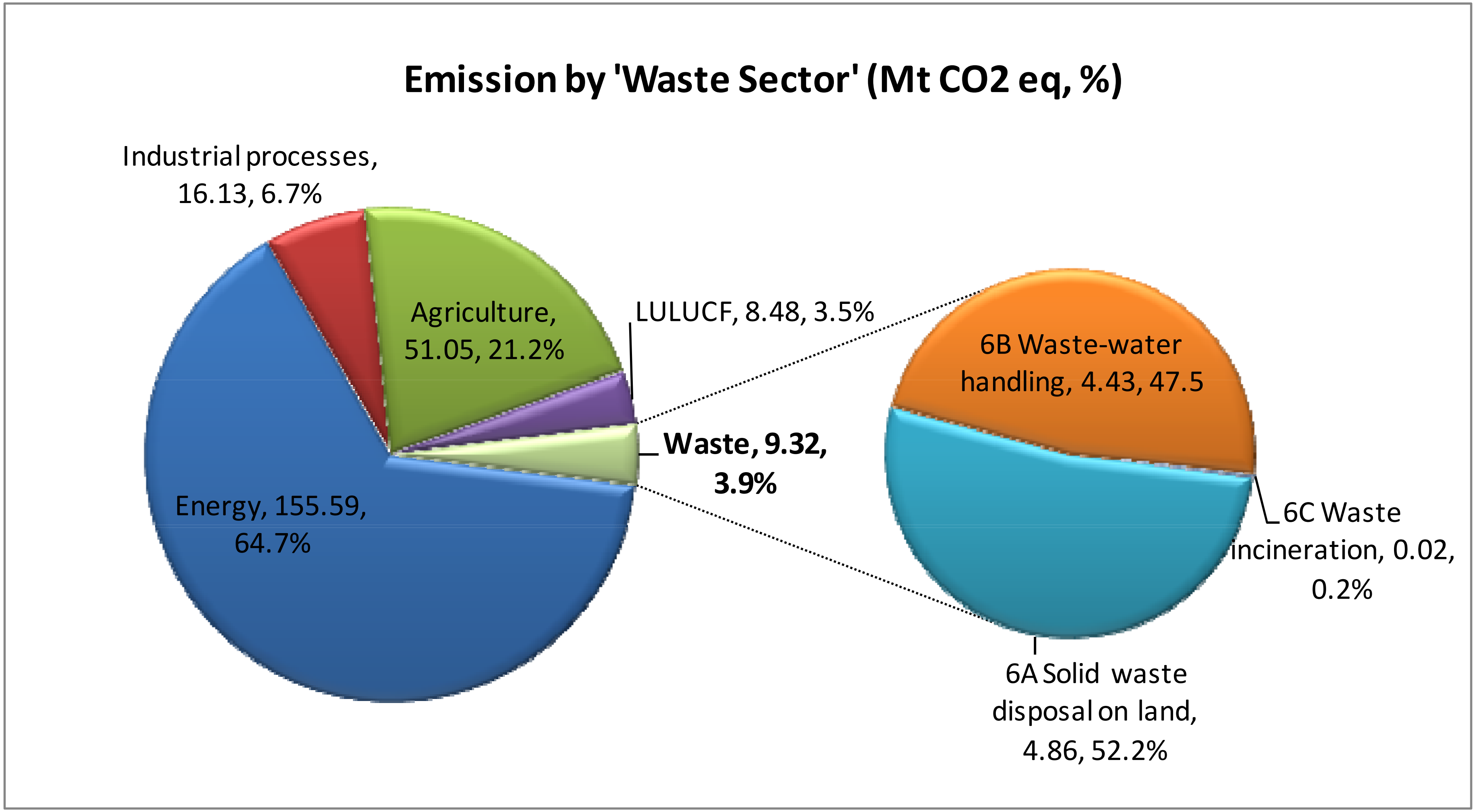
Source Sink and Categories

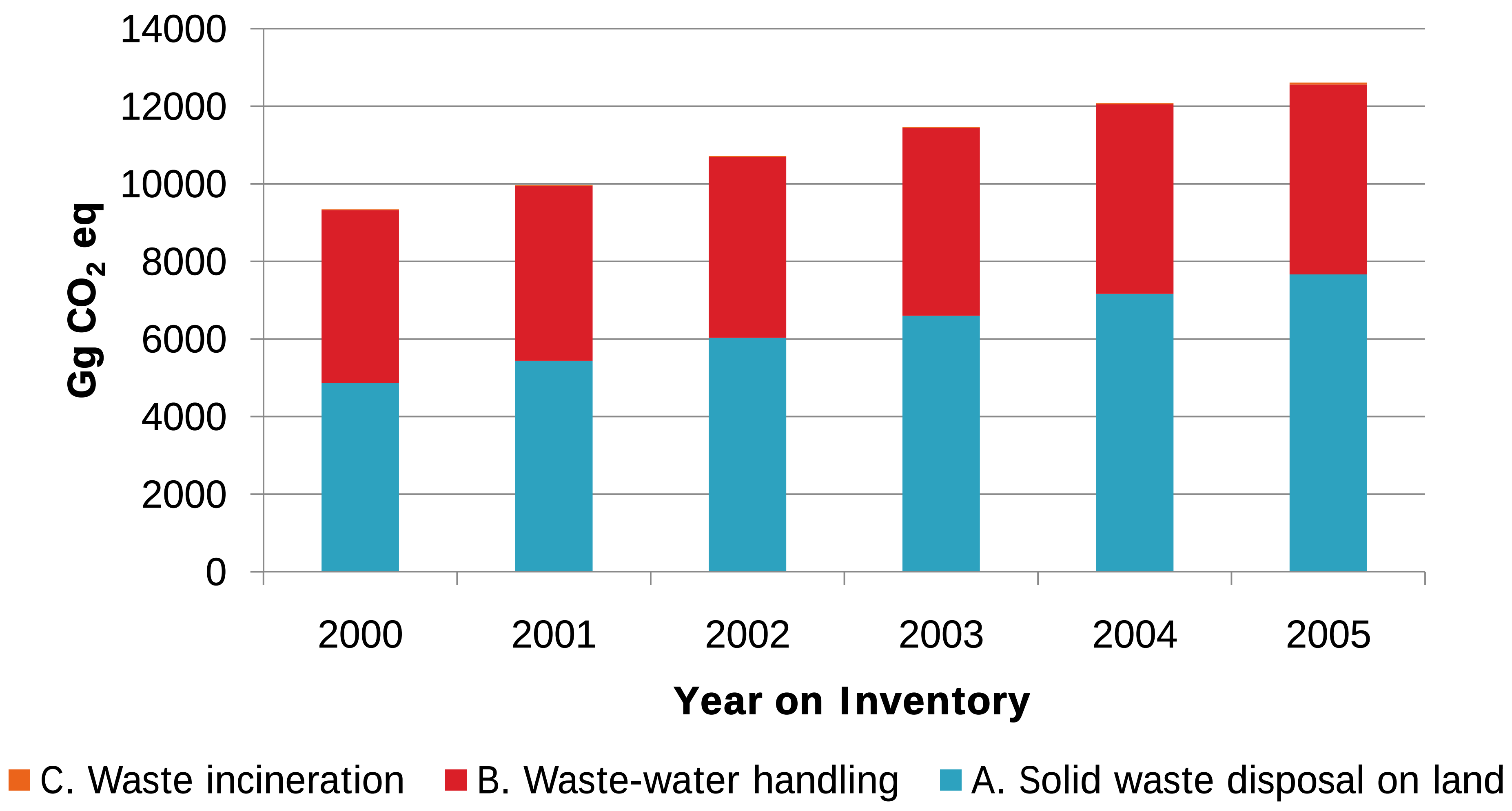
(the Revised 1996 IPCC Guidelines)





CO_2 equivalent in 2000: TIER 2

GHG Emissions from waste sector (2000-2005)



6A Solid waste disposal on land	
6A1 CH_4 Emission, Gg/yr	**Tier 1**: CH_4 Emission = $[(MSW_T*MSW_F*L_o)-R]*(1-OX)$
	Tier 2: CH_4 Emission $Q_{T,x} = k*R_x*L_O\ e^{-k(T-x)}$ $Q_T = \sum Q_{T,x}$ (for x = initial year to T)

TIER 1; where, MSW_T = Total MSW Generated, Gg/yr, National information

MSW_F = Fraction of MSW disposed at SWDS, National information

L_o = Methane Generation Potential

= $[MCF*DOC*DOC_F*F*16/12$ (Gg CH_4/Gg Waste)]

MCF = Methane Correction Factor, Fraction, Defaults (LF=1.0 , OD=0.4)

DOC = Degradable Organic Carbon, Fraction (Gg C/Gg MSW) , 0.12

DOC_F = Fraction DOC Dissimilated : DOC_F , 0.77

F = Fraction by Volume of methane (CH_4) in landfill gas 0.55

R = Recovered methane (CH_4), Gg/yr) , 0

OX = Oxidation Factor (Fraction) , 0

TIER2; where, $Q_{T,x}$ = the amount of methane generated in the current year (T) by the waste R_x

x = the year of waste input

L_o = methane generation potential (m^3/Mg of refuse)

R_x = the amount of waste disposed in year x (Mg)

T = current year

6A: Waste disposal on land

Activity data

Description		Source
-MSW quantity and characteristics	- Amount of MSW generation/ collection/ recycled - Population - Amount of MSW disposal at site - National GDP statistics - Waste compositions and characteristics	**Use Local information**
-Disposal Management:	- Opening/closing year of SWDS - Landfill operation (OD, sanitary LF, semi-aerobic LF) - Waste management and policies at both national and local levels - Technology approaches and development	**Use Local information**

***** Interpolation (for the incomplete AD) *****

6A: Waste disposal on land

Emission Factor (EF)

EF	Defaults 1996 IPCC GL	Thailand
Methane correction factor (MCF)	**Waste Disposal Method — MCF** Landfill — 1.0 OD-deep (d > 5m) — 0.8 OD-shallow (d < 5m) — 0.4	**Waste Disposal Method — MCF** Landfill — 1.0 OD — 0.5
Fraction of DOC in MSW (DOC)	(calculation from waste compositions)	0.14 (National report)
Fraction DOC Dissimilated (DOC_F)	0.77	0.77
Fraction by Volume of methane in landfill gas (F)	0.50	0.55
Recovered methane (R)	0	0
Oxidation factor (X)	0	0

$$DOC = 0.4*\%\ MSW_{\text{papers and textiles}} + 0.17*\%MSW_{\text{gardenwaste \&other non-food organic waste}} + 0.15*\%MSW_{\text{food waste}} + 0.30*\%MSW_{\text{wood or straw}}$$

Emission Factor (EF)

Emission Factor (Tier 2)		Defaults 1996 IPCC	Thailand		
				SNC (2000-2005)	INC (1994)
L_o, m^3/Mg of refuse	Wet climate	180-200	Metro. LF	121.40	121.40
	Medium moist. climate	160-189	LF	103.7	130.22
	Dry climate	140-160	OD	60.7	70.42
k, 1/yr	LF	0.003-0.40	LF	0.07	0.04
	OD		OD	0.03	0.03
CH_4 density, kg/m^3		-	-	0.714 (@ STP)	-

6B Wastewater Handling	
6B1 CH_4 Emission from domestic ww, kg	$WM = \sum_i (TOW_i \times EF_i - MR_i)$ Emission Factor = Bo x Weighted Average of MCF
6B2 N_2O Emission from human sewage, kg	$N_2O(s) = Protein \times Frac_{NPR} \times NR_{people} \times EF6$
6B3 CH_4 Emission from industrial ww, kg	$WM = \sum_i (TOW_i \times EF_i - MR_i)$ Emission Factor = Bo x Weighted Average of MCF

Domestic WW; Where:

WM = Total methane emissions from domestic wastewater (kg CH_4)
TOW_i = Total organic waste for domestic wastewater type i (kg DC/yr
EFi = Emission factor for domestic wastewater type i (kg CH_4 /kg DC)
MR_i = Total amount of methane recovered or flared from domestic wastewater type I, (kg CH_4)
Bo = Maximum methane producing capacity (kg CH_4 /kgBOD)
MCF = Methane conversion factor (Fraction)

Industrial WW; Where:

WM = Total methane emissions from industrial wastewater (kg CH_4)
TOW_i = Total organic waste for industrial wastewater type i (kg DC/yr)
EF_i = Emission factor for industrial wastewater type i (kg CH_4 /kg DC)
MR_i = Total amount of methane recovered or flared from industrial wastewater type i (kg CH_4)
Bo = Maximum methane producing capacity (kgCH_4/kgCOD)
MCF = Methane conversion factor (Fraction)

Human Sewage; Where:

Protein intake = Annual per capita protein intake (kg/person/yr)
NR_{people} = Number of people in country
$Frac_{NPR}$ = Fraction of nitrogen in protein (kg N/kg protein)
EF6 = Emission factor (kgN_2O-N/kg sewage-N produced)

6B: Wastewater Handling

Activity data

Description		Source
6B.1 Domestic wastewater	- Population - BOD/person/d - National GDP statistics - Wastewater characteristics - Technology approaches and development	**Use Local information**
6B.2 Industrial wastewater	- Wastewater quantity and organic concentration (as COD) - Wastewater management and policies at both national and local levels - Technology approaches and development	**Use Local information**
6B.3 Human sewage	- Protein intake - Fraction of nitrogen in protein - Population	**Use Local information And Revised 1996 IPCC GL**

***** Interpolation (for the incomplete AD) *****

Emission Factor (EF)

EF	Defaults Revised 1996 IPCC GL	Thailand
Maximum methane producing capacity (Bo)	• 0.25 $kgCH_4/kgCOD$ or • 0.6 kgCH4/kgBOD	-
Methane conversion factor (MCF)	(0-0.8 Depended on technologies)	(0-1 Depended on technologies) **Expert judgment**
Fraction of nitrogen in protein ($Frac_{NPR}$)	0.16 kg N/kg protein	-
Emission factor (EF6)	0.01 $kgN_2O\text{-}N/kg_{sewage}\text{-}N_{produced}$	-
Protein intake		21.206 kg/person/year

MCF for industrial wastewater

Type of treatment and discharge pathway	Defaults MCF (Revised 1996 IPCC GL)	MCF (Thailand)
Anaerobic covered lagoon	0.8	0.74±0.12
Upflow anaerobic sludge blanket (UASB)	0.8	0.81±0.08
Anaerobic filter	0.8	0.76±0.10
Anaerobic tank	0.8	0.72±0.11
Anaerobic pond	0.2	0.56±0.18
Anaerobic digester	0.8	0.76±0.10
Septic tank	0.5	0.58±0.19
Stabilization pond	0.2	0.33±0.17
Polishing pond	0	0.15±0.17
Aerated lagoon	0	0.09±0.09
Activated sludge	0	0.05±0.06
Constructed wetland	0.3	0.17±0.12
Oxidation ditch	0	0.14±0.12
Sequencing batch reactor	0	0.12±0.14
Storage pond	0.2	0.23±0.14

Expert Judgment

MCF for domestic wastewater

Type of treatment and discharge pathway	Defaults MCF (Revised 1996 IPCC GL)	MCF (Thailand)
Stabilization pond	0.2	0.22±0.15
Oxidation ditch	0.0	0.08±0.08
Aerated lagoon	0.0	0.06±0.06
Activated sludge	0.0	0.03±0.05
Contact stabilization activated Sludge	0.0	0.04±0.07
Two-stage activated sludge process	0.0	0.03±0.05
Combination of fixed activated sludge	0.0	0.08±0.07
Rotating biological contractor	0.0-0.3	0.12±0.06
Constructed wetland	0.3	0.20±0.11
Anaerobic filter	0.8	0.69±0.17
Septic tank	0.5	0.57±0.16
Latrine	0.1	0.10±0.00

Expert Judgment

6C Waste incineration	
6C1 CO_2 Emission, Gg/yr	CO_2 Emissions = $\Sigma i\ (IW_i * CCW_i * FCF_i * EF_i * 44/12)$
6C2 N_2O Emission, Gg/yr	N_2O Emissions = $\Sigma_i\ (IW_i * EF_i)*10^{-6}$

CO_2 Emission; where, i= MSW: Municipal Solid Waste HW: Hazardous Waste

CW: Clinical Waste SS: Sewage Sludge

IW_i = Amount of Incinerated Waste of Type i (Gg/yr)

CCW_i = Fraction of Carbon Content in Waste of Type i

FCF_i = Fraction of Fossil Carbon in Waste of Type i

EF_i = Burn Out Efficiency of Combustion of Incinerators for Waste of Type i (Fraction)

44/12 = Conversion from C to CO_2

N_2O Emission,; where. IW_i = Amount of Incinerated Waste of Type i (Gg/yr)

EF_i = Aggregate N_2O Emission Factor for Waste Type i (kg N_2O/Gg)

6C: MSW Incineration

Activity data

Description		Source
-MSW quantity and characteristics	- Amount of MSW generated/collection/incinerated - National GDP statistics - Waste compositions and characteristics	**Use Local information**
- Incineration Management:	- Opening/closing year of incinerator - Monitoring of plant operation - Waste input (as wet/dry basis) - monitoring of air emission information - design and specification of incinerattor - Policy of waste management	**Use Local information**

***** Interpolation (for the incomplete AD) *****

Emission Factor - 6C Waste incineration

CO_2 Emission

EF	Defaults (Revised 1996 IPCC GL)	Thailand (SNC)
C content of waste (MSW,wet)	Waste Type / %C: MSW, wet waste: 33-55 (40%) Sewage Sludge, dry matter: 10-40 (30%)	47.0-49.7 %
Fossil carbon as % of Total carbon	Waste Type / % Fossil Carbon: MSW, wet waste: 30-50 (40%) Sewage Sludge: 0%	20.8-21.1 %
Efficiency of combustion,%	Waste Type / % Eff.combustion: MSW: 95-99 (95%) Sewage Sludge: 95%	95%

N_2O Emission

Type of incineration plant	Defaults (Revised 1996 IPCC GL)	Thailand (SNC)
Hearth or grate	Waste Type / kgN_2O/Gg waste: MSW, dry waste: 40-150 (Jap., wet) (40) Sewage Sludge, dry: 400 (Jap., wet)	29.0%

Possible Reduction Options of GHG Emissions for Solid Waste Management

Policy / Practice / Management :	**Waste generation rate**	Control of waste generation rate less than 1 kg/person-d
	Recycling	3Rs: Separation of usable and recyclable materials.
Technology:	**Methane oxidation Reduction**	Management of landfill cover soil to reduce the amount of methane emission from landfill.
	Power generation	Landfill gas recovery
	Anaerobic digestion	Methane production and recovery
	Compost	Conversion of organic carbon to CO_2
	Semi-aerobic Landfill	Promote aerobic condition in the landfill cell

Possible Reduction Options of GHG Emissions for Wastewater Handling

Policy / Practice / Management :	**Water reduction**	Wastewater reduction
	Recycle and reuse water	Recycle / Reuse treated wastewater
Technology:	**Aerobic treatment**	Avoidance of methane production
	Methane recovery and utilization (WTE)	■ Anaerobic digester reactors are needed, not necessarily cheap. ■ Methane capture and recovered for energy production.

Mitigation: Assumptions and calculation methods

- **6A: Solid waste disposal on land:**

  $$CH_4 \text{ Emission} = [(MSW_T * MSW_F * L_o) - R] * (1 - OX)$$

- **6B: Wastewater Handling:**

6B1 Domestic ww, kg	CH_4 Emission = $\sum_i (TOW_i \times EF_i - MR_i)$ Emission Factor = Bo x Weighted Average of MCF
6B2 Human sewage, kg	$N_2O(s)$ Emission = $Protein \times Frac_{NPR} \times NR_{people} \times EF6$
6B3 Industrial ww, kg	CH_4 Emission = $\sum_i (TOW_i \times EF_i - MR_i)$ Emission Factor = Bo x Weighted Average of MCF

- **6C: MSW incineration**:

  $$CO_2 \text{ Emissions} = \Sigma i\ (IW_i * CCW_i * FCF_i * EF_i * 44/12)$$

  $$N_2O \text{ Emissions} = \Sigma i\ (IW_i * EF_i) * 10^{-6}$$

Mitigation: Assumptions and calculation methods

- **BAU Scenario:** (6A: Solid waste disposal on land, 6C: MSW incineration)

Assumption

- Waste generation rate are related to country's GDP through econometric model
- Waste generation are derived from population and waste generation rate (kg/cap.-d).
- For future prediction, we should define the country population growth rate and country GDP growth.
- Calculate the amount of waste generation per year (by multiplying waste generation rate with number of population)
- The amount of waste disposal at SWDS (LF and OD) are calculated from the amount of waste generation minus the amount of recycled waste and multiply with the ratio of OD and LF

Mitigation: Assumptions and calculation methods

- **BAU Scenario:** (6A: Solid waste disposal on land, 6C: MSW incineration)

Assumption

- Econometric equations to forecast the amount of waste generation rate in the future are given

$$Y_{\text{Waste generation, kg/cap.-d}} = 0.454 + (\text{Per capita GDP} * 2.916)$$

Where, $Y_{\text{waste generation}}$ = waste generation rate, kg/person-d

Per capita GDP = GDP per capita, at different GDP growth rate 2, 4 and 6% per year

- Calculated the amount of methane emission per year (6A Solid waste disposal on land (Tier 1) from 1996 IPCC Revised Guideline by

$$CH_4 \text{ Emission (Gg/y)} = [(MSW_T * MSW_F * L_o) - R] * (1 - OX)$$

Mitigation: Assumptions and calculation methods

Prediction: 1993-2008

Year	population	GDP, M Bht.	per capita GDP	Waste generation rate, kg/cap.-d	Waste generation, t/d
1993	58,336,072	2,470,908	0.04	0.53	30640
1994	59,095,419	2,692,973	0.05	0.56	33008
1995	59,460,382	2,941,736	0.05	0.58	34492
1996	60,116,182	3,115,338	0.05	0.60	36029
1997	60,816,227	3,072,615	0.05	0.61	37102
1998	61,466,178	2,749,684	0.04	0.61	37246
1999	61,661,701	2,871,980	0.05	0.61	37879
2000	61,878,746	3,008,401	0.05	0.62	38,085
2001	62,308,887	3,073,601	0.05	0.62	38,643
2002	62,799,872	3,237,042	0.05	0.62	39,225
2003	63,079,765	3,468,166	0.05	0.62	39,240
2004	61,973,621	3,688,189	0.06	0.64	39,956
2005	62,418,054	3,858,019	0.06	0.63	39,221
2006	62,828,706	4,059,645	0.06	0.64	40,012
2007	63,038,247	4,259,633	0.07	0.64	40,332
2008	63,389,730	4,370,056	0.07	0.65	41,023

$$Y_{\text{Waste generation, kg/cap.-d}} = 0.454 + (\text{Per capita GDP} * 2.916)$$

SUMMARY OUTPUT

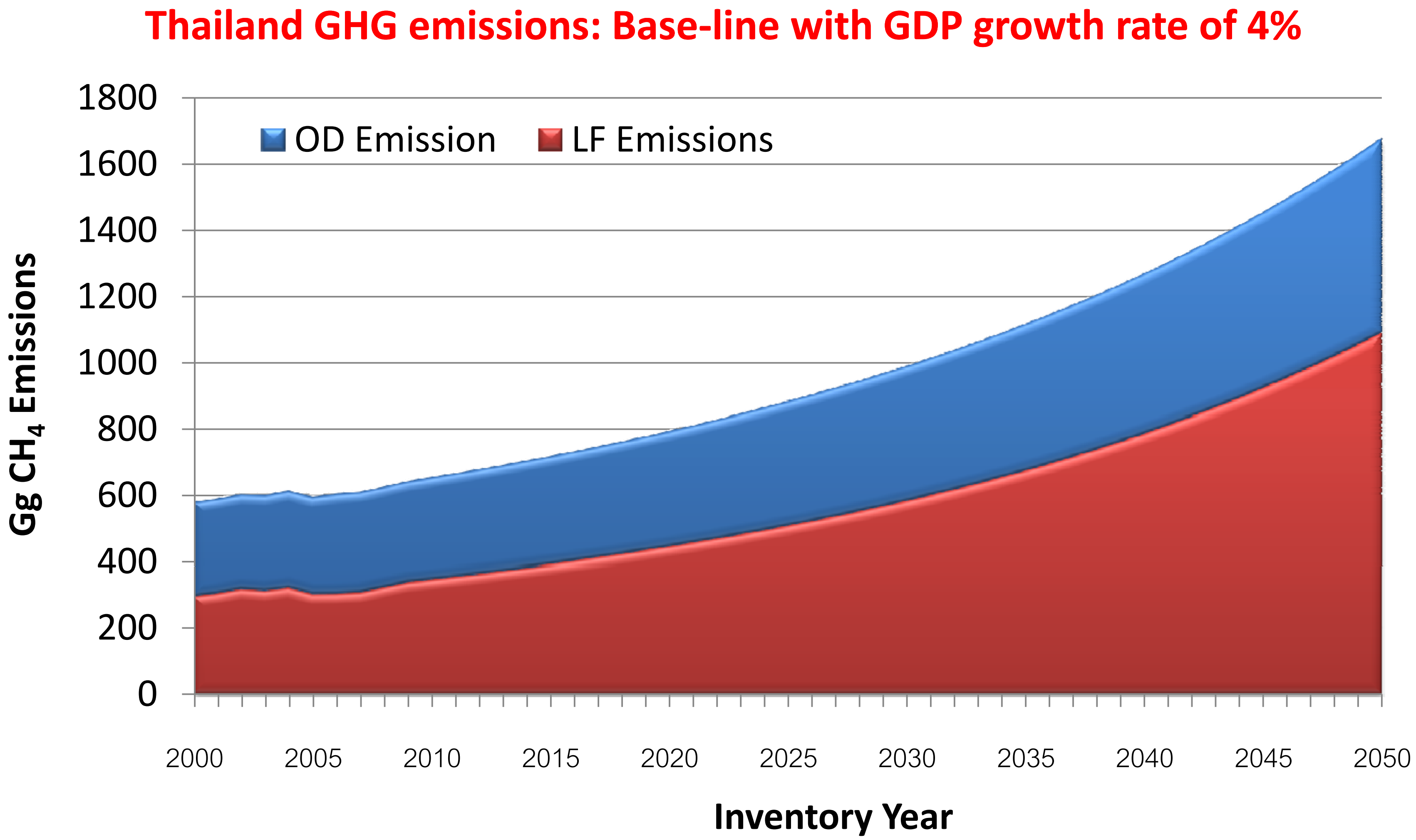
Regression Statistics	
Multiple R	0.750
R Square	0.563
Adjusted R Square	0.532
Standard Error	0.022
Observations	16

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.009	0.009	18.036	0.001
Residual	14	0.007	0.000		
Total	15	0.016			

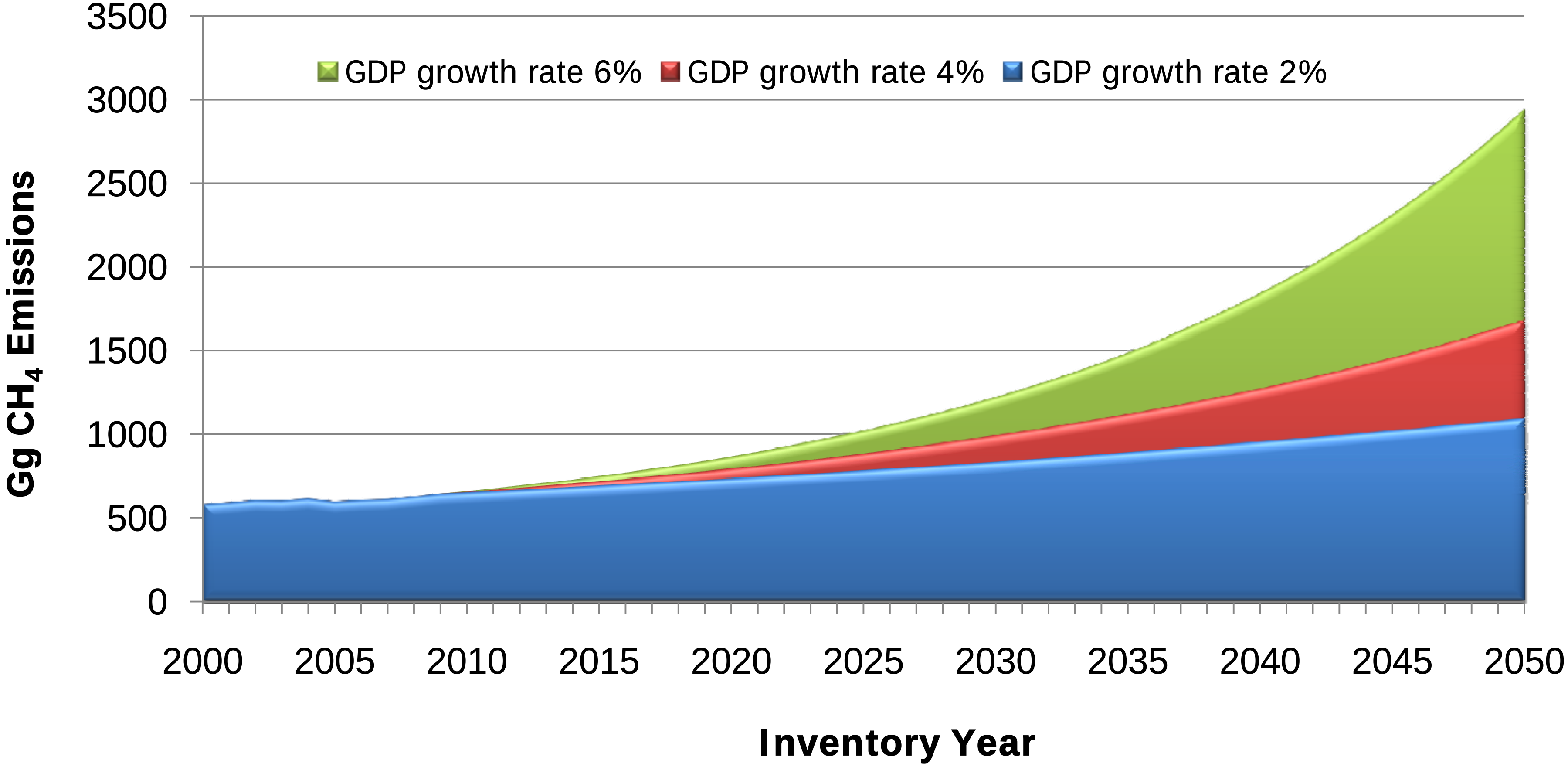
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.454	0.037	12.201	0.000	0.375	0.534	0.375	0.534
Per capita GDP	2.916	0.687	4.247	0.001	1.444	4.389	1.444	4.389

Mitigation: Assumptions and calculation methods



Mitigation: Assumptions and calculation methods

Thailand GHG emissions: Base-line with GDP growth rate of 2, 4 and 6%



Mitigation: Assumptions and calculation methods

- **BAU Scenario:** (6B: Wastewater Handling)

Assumption

- Wastewater generation (or total organic waste) are changed according to population (Domestic WW and Human sewage) and country's GDP (Industrial WW)
- Wastewater generation are forecasted from the econometric model using GDP Per Capita, population and wastewater generation rate (kg BOD/cap.-d)

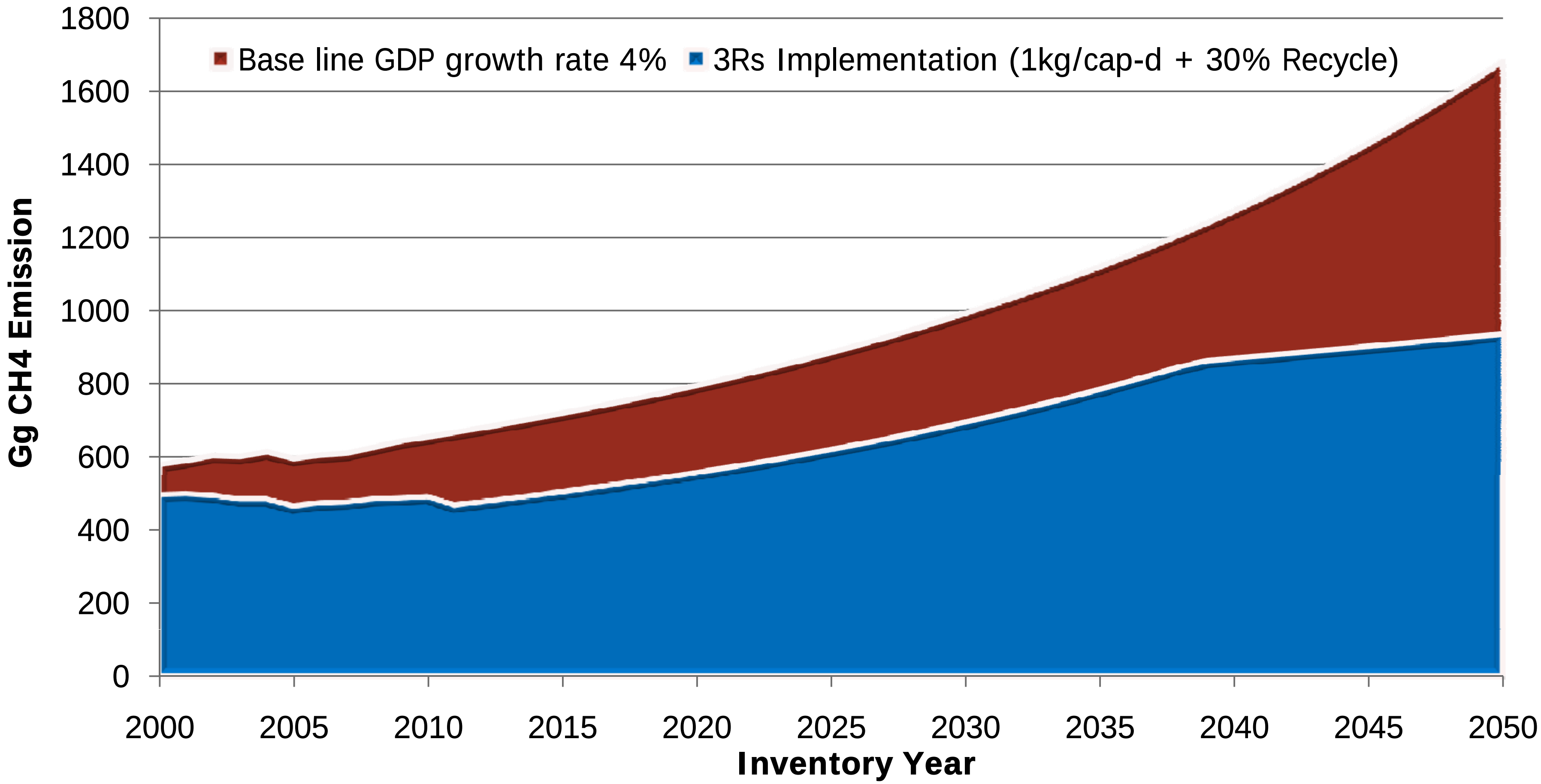
Assumption of Mitigation Options of GHG Emissions for Solid Waste Management

Management:	**Waste generation rate**	Control of waste generation rate less than 1 kg/person-d	■Applied at year that have waste generation rate > 1 kg/person-d and keep constant to the end
	Recycling	■Separation of usable and recyclable materials.	■ Increasing recycle rate: Increasing as the trend of previous statistics ■ Constant recycle rate (30%): When the recycle rate increasing to 30% (government policy) and keep constant to the end of projection.
Technology:	**Organic Treatment (Anaerobic digestion, Composting)**	■ Anaerobic digester reactors are needed, not necessarily cheap. ■ Composting: Simple and cheap	■ Amount of waste input is the remained waste after 3Rs implementation (1 kg/person-d + constant recycle rate at 30%), ■Forecast the organic fraction in MSW for the compost/AD from the waste statistics as a linear regression at maximum ration of 30% (Europe countries application), ■Forecast ration of composting and AD increasing rate base on country data and projected as a linear regression. The ratio of organic waste (end of projection) to be compost and AD 70 and 30% consequently. (Application of AD at 30% is define as according to the developed countries in Europe).

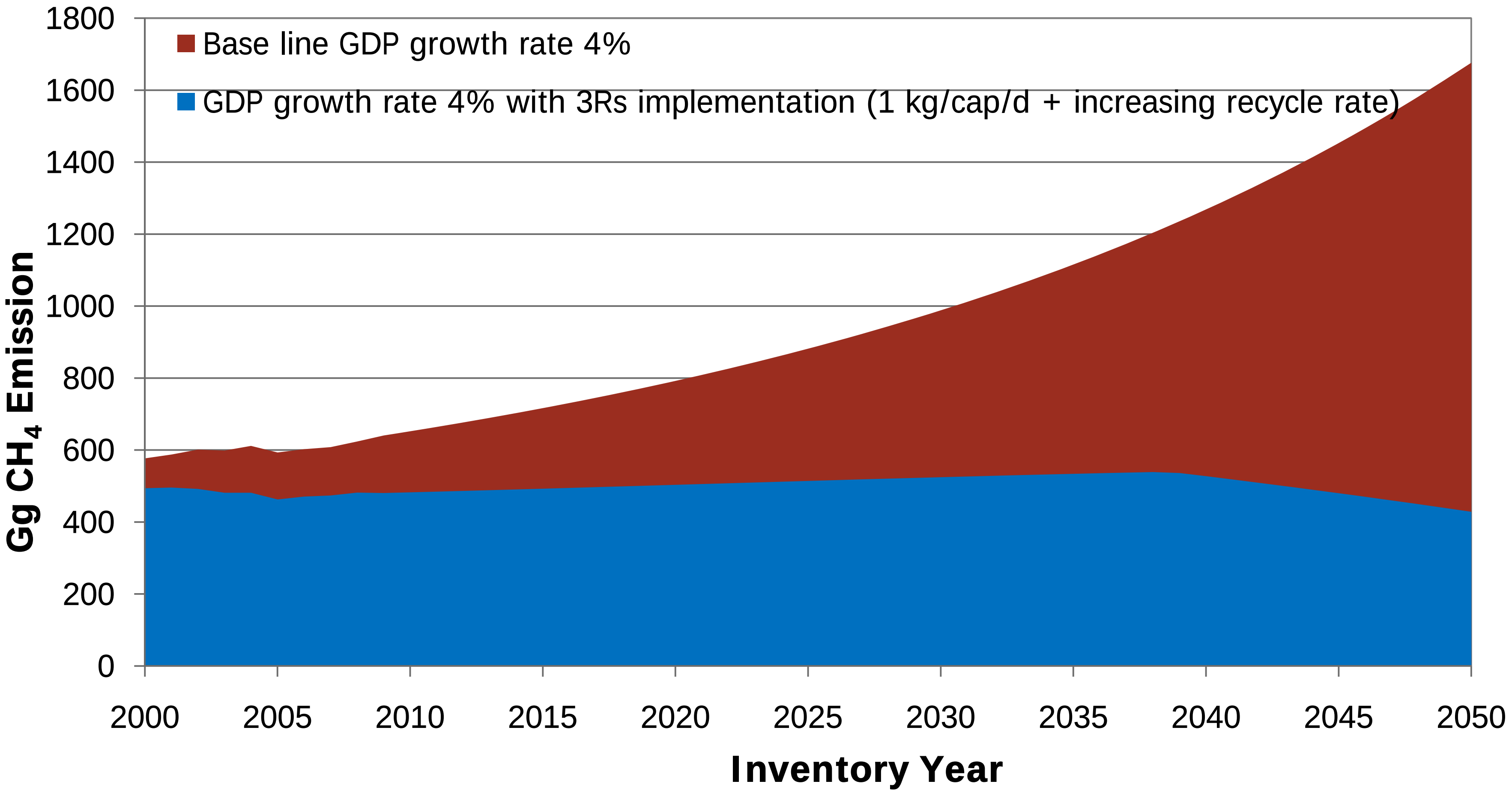
Assumption of Mitigation Options of GHG Emissions for Solid Waste Management

Technology:	**Power generation**	■ Landfill gas recovery ■ Digestion methane-capture.	■ Amount of waste input is the remained waste after 3Rs implementation (1 kg/person-d + constant recycle rate at 30%) + organic treatment ■ Forecast the increasing ratio of large sanitary LF (waste in place > 1 Mton) from the waste landfill site statistics (National data, 2005) and projection as a linear regression, ■ Define the efficiency of biogas (methane) recovery from LF at 75% of generated biogas
	Semi-aerobic Landfill	Promote aerobic condition in the disposed waste cell whereas generated leachate is drainage as quick as possible.	■Amount of waste input is the remained waste after 3Rs implementation (1 kg/person-d + constant recycle rate at 30%) + organic treatment and landfill gas to energy (LFGTE) application ■ Forecast the increasing ration of semi-aerobic landfill approaches from the previous national report as a linear regression. Define that at the end of projection, all LF approaches change to use semi-aerobic LF technology ■ Define the methane reduction ration after applied semi-aerobic LF will be decreasing to 50% of generated methane

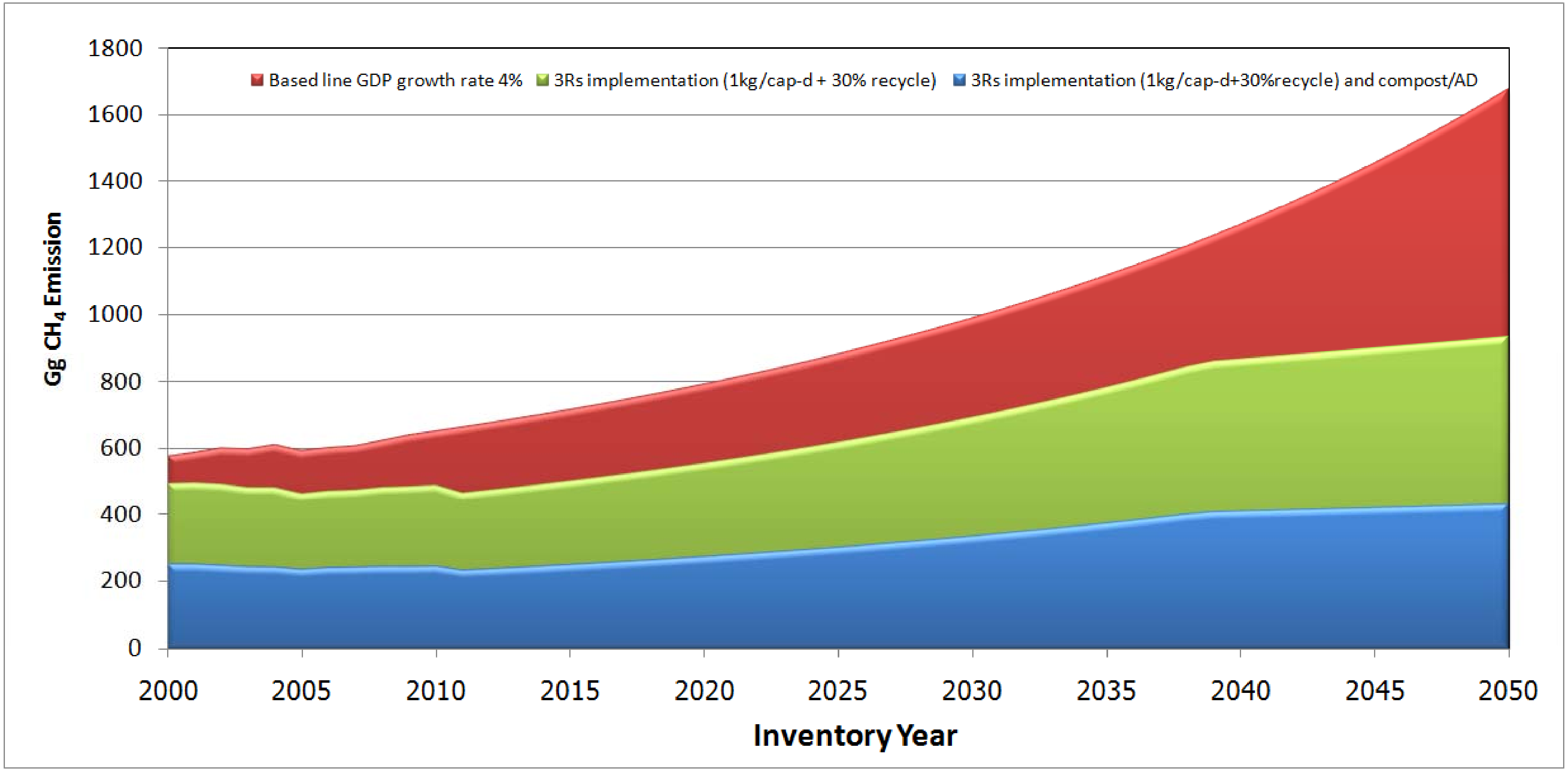
Policy: 3Rs Implementation (1kg/person-d with constant waste recycling rate of 30%)



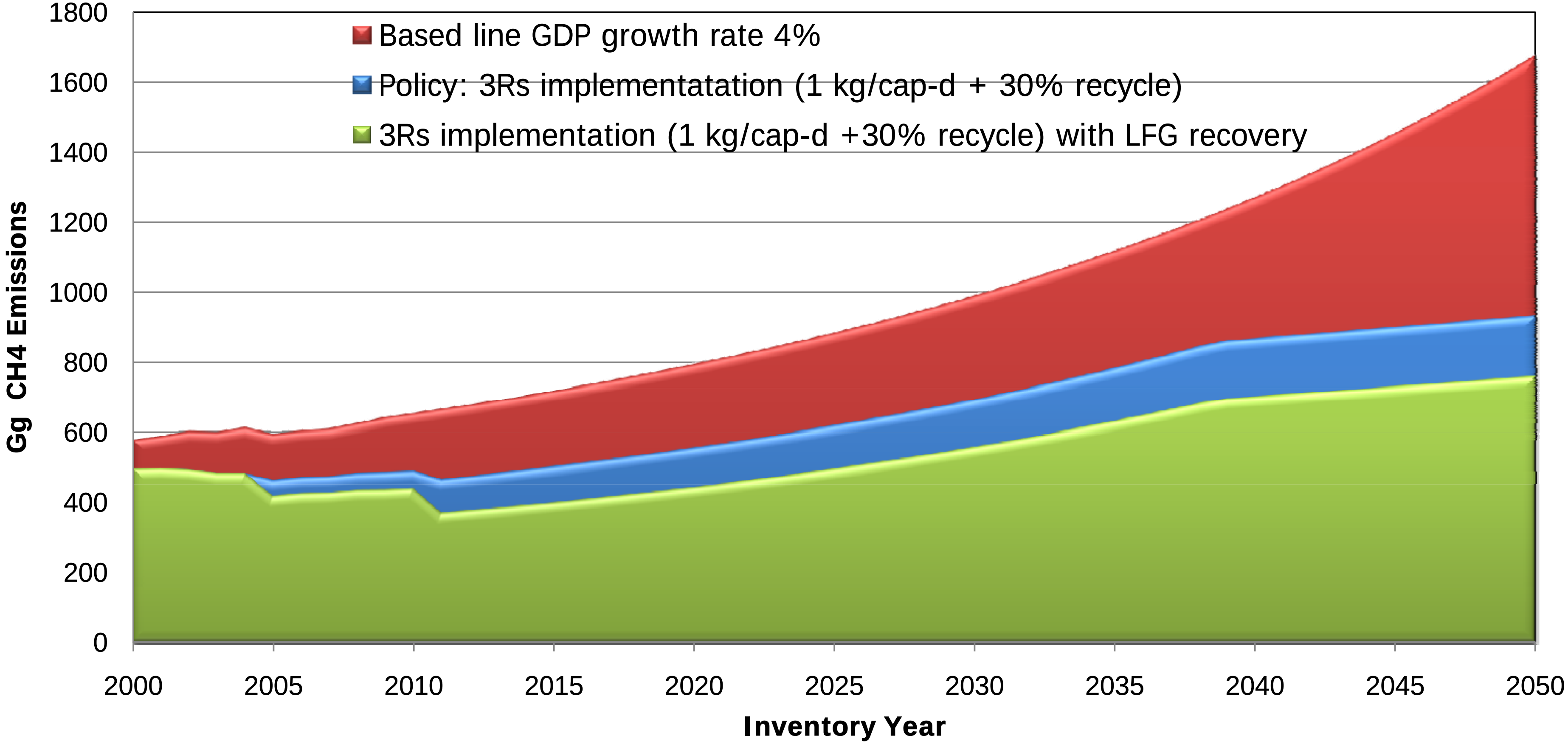
Policy: 3Rs Implementation (1kg/person-d with increasing waste recycling rate)



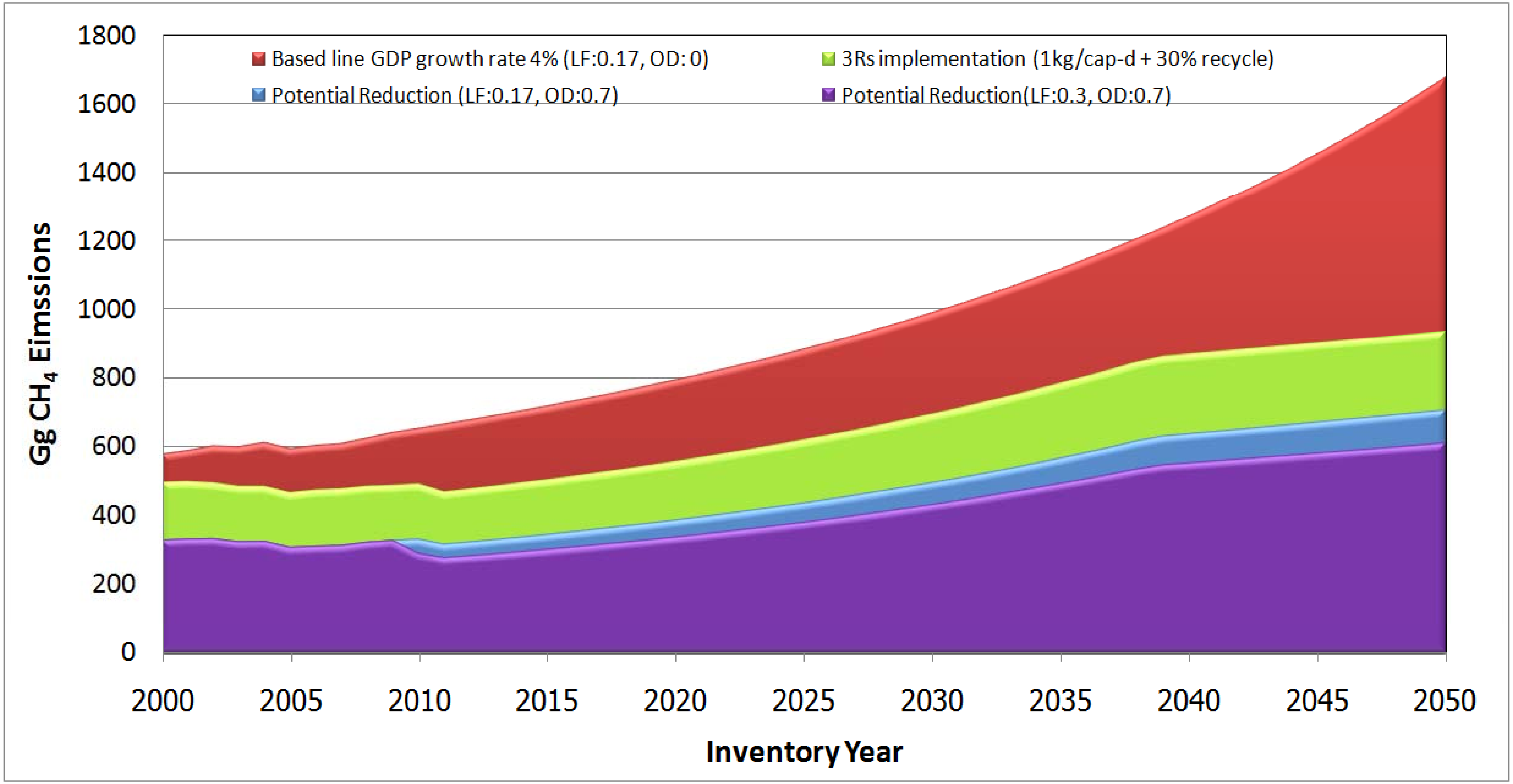
Policy: 3Rs Implementation (1kg/person-d with constant 30% waste recycling rate) with compost/AD



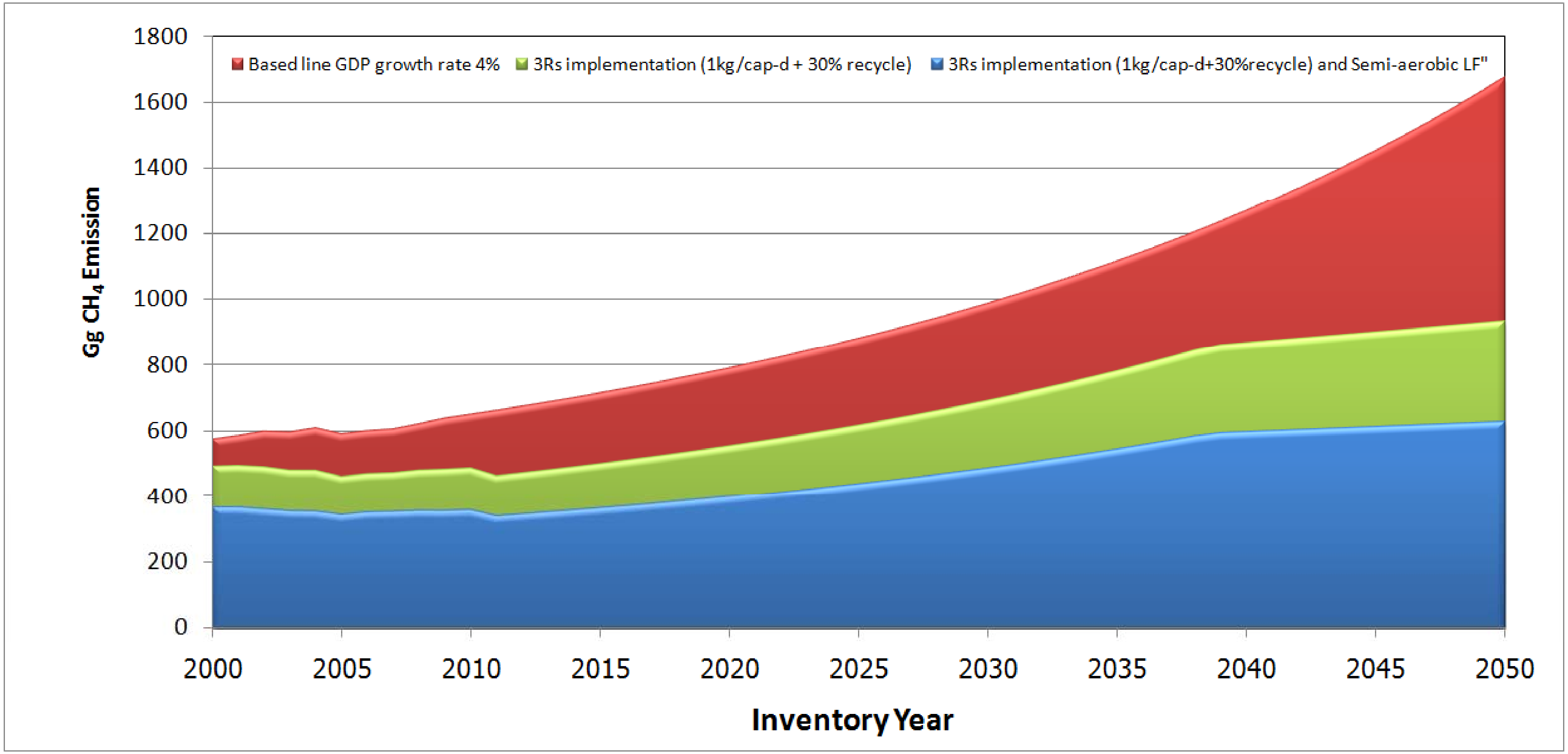
Technology: 3Rs Implementation + Landfill gas recovery (wastes in placed more than 1,000,000 tons)



Technology: 3Rs Implementation with methane oxidation potential to disposal site



Technology: 3Rs Implementation with Semi-aerobic landfill application to sanitary landfill



- The End –

Thank you