Current Status of IAM in Korea in Support of Transboundary Air Pollution Assessment Over Northeast Asia

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December 8, 2016

NEASPEC Transboundary Air Pollution Project Expert Consultation Meeting, Seoul, Korea
Content

1. Present Status of TAP IAM-related work in Korea

2. An idea on a possible collaborative framework on TAP IAM in NE Asia
Background

: Linkage between Climate Change and Air Quality

D. Jacob, 2009
## Integrated Assessment Model Development (Korea)

<table>
<thead>
<tr>
<th>Title</th>
<th>Institute</th>
<th>Model</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Integrated Environmental Strategy (IES)</td>
<td>KEI-US EPA</td>
<td>PAGE, CMAQ, BENMAP</td>
<td>No energy model, Closed system, Optimization mode</td>
</tr>
<tr>
<td>Greenhouse Gases and Air pollutants Interaction and Synergy (GAINS)-Korea</td>
<td>NIER/KU- IIASA</td>
<td>GAINS - Emissions, Transport - Cost - Impact</td>
<td>No energy model, Scenario mode, Linear air quality transport, Open system, Fast source apportionment, 1st admin level</td>
</tr>
<tr>
<td>Climate-Air Quality Integrated Modeling (ICAMS)</td>
<td>NIER(SNU, KU) - NIES/IIASA</td>
<td>MESSAGE/AIM, GEOSChem/CMAQ, BENMAP</td>
<td>No policy feedback, Offline-linking (less integration), Strong Science, Multi-domain (Global-National)</td>
</tr>
</tbody>
</table>

- **Pros vs. Cons**
ICAMS
Climate Change and Air Quality Study using NIER/SNU-ICAMS

Konkuk Univ. (KU)

New future emission (NIER) Scenario

2014~2016 (3rd Stage)

Seoul Natl Univ. (SNU)

ozone-PM precursors

greenhouse gases

input meteorology

NCAR CCSM v3 (GCM)

GEOS-Chem (CTM)

for global ozone-PM

MM-5 or WRF RCM

CMAQ for regional ozone-PM

NIER*

* National Institute of Environmental Research
New East Asia Future Emission Scenarios for ICAMS

**Features**
- Up to 2100
- LLCPs and SLCPs emissions
- Global and Regional
- CC and AQ modeling friendly

J Woo, TF HTAP, 2014
* Comprehensive Regional Emissions for Atmospheric Transport Experiments

**Baseline Emission Inventory : NIER/KU-CREATE**

1. Emission Inventory : Improve GAINS-Asia emissions using updated national data, MEGAN/BlueSky emissions model
2. Year 2009/2010, Asia regions, ~300 source categories
3. Pollutants: CO₂, CH₄, NOₓ, N₂O, PM₁₀, PM₂.₅, SO₂, VOC, NH₃, CO, BC, OC, Mercury
4. Anthropogenic, Biogenic, Biomass burning
5. Emissions processing friendly
Energy Projection

Energy Demand of SSP Scenarios

Energy projection using MESSAGE

Primary Energy

Fuel Mix in Power sector

Final Energy

Source: IIASA
Implementation of control policy

1. **NFC (No Further Control)**: No further control after 2010. All controls will be phased-out as their life time reaches.
2. **CLE_a (Current Legislation)**: Maintain 2010 level + Implement some planned national control policies (~ Yr 2013)
3. **CLE_b (Current Legislation)**: CLE_a + Implement all planned control policies and technologies (with regional action plan)
4. **MFR (Maximum Feasible Reduction)**: Most stringent control technologies and reduction efforts will be introduced. (with INDC & Announcement on Climate Change)
Emission pathway for each scenario of China
Province level emissions for each 2050 scenarios

2010 Base year

NOx

NFC

CLE_a

CLE_b

MFR
Impact of Climate Change on Regional Air Quality

Integrated Climate Change and Air Quality Modeling Framework (ICAMS, NIER 2011)

Global and regional emission processing system (KU-EPS* and SMOKE-Asia)

* KU-EPS: Korea University Emission Processing System

- Probability of high ozone events exceeding 60 ppbv for summer maximum 8-h average over East Asia

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<tr>
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<tbody>
<tr>
<td>2000</td>
<td>10.8%</td>
<td></td>
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</tr>
<tr>
<td>2020</td>
<td>24.9%</td>
<td>26.3%</td>
<td>28.3%</td>
<td>20.0%</td>
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<tr>
<td>2050</td>
<td>20.7%</td>
<td>26.5%</td>
<td>35.3%</td>
<td>15.5%</td>
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<tr>
<td>2100</td>
<td>6.1%</td>
<td>11.4%</td>
<td>26.7%</td>
<td>6.7%</td>
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<tr>
<th>IPCC SRES Scenarios</th>
<th>A1T</th>
<th>A1B</th>
<th>A1FI</th>
<th>B2</th>
<th>B1</th>
<th>A2</th>
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<td>2020</td>
<td>24.9%</td>
<td>26.3%</td>
<td>28.3%</td>
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<td>22.3%</td>
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<tr>
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<td>20.7%</td>
<td>26.5%</td>
<td>35.3%</td>
<td>15.5%</td>
<td>2.7%</td>
<td>33.5%</td>
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<tr>
<td>2100</td>
<td>6.1%</td>
<td>11.4%</td>
<td>26.7%</td>
<td>6.7%</td>
<td>1.3%</td>
<td>41.8%</td>
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Courtesy of R. Park
GAINS-Korea
GAINS-Korea: An CC-AQ Integrated Assessment Framework for Korea

Figure 2.2: The iterative concept of the GAINS optimisation. Amann, 2011
CAMx Modeling for S-R Matrix

Modeling domain

Domain 1: 54km
Domain 2: 18km

Definition of S-R region

- Receptor (17 regions)
  Metropolitan cities (8 cities) and provinces (9 regions)
- Source (19 regions)
  Same as receptor regions with outside of S. Korea countries (China, N. Korea and Japan)

- Meteorological data: MM5 (year 2005 from NIER)
- Emissions: GAINS-Korea (CAPSS2010), CREATE
- Emissions processing: SMOKE-Asia (Woo et al., 2012) linking with GAINS
- Air quality model: CAMx version 6.0 with PSAT/OSAT (Particulate/ozone Source Apportionment Technology)
  - Model option: EBI chemistry solver with CB05 mechanism, ACM2 diffusion, PPM advection scheme
China Emission Scenario in GAINs-Korea S-R Matrix
- ECLIPSE CLE

*CO emissions divided by factor of 5
Emission Trends for Pre/Post 2010: Korea
- Emissions Change due to 1st and 2nd Phase of SAQMP

SO2

Emissions Reductions:
- 1st SAQMP: 70,188
- 2nd SAQMP: 48,782

Remaining Emissions:
- 1st SAQMP: 37,130
- 2nd SAQMP: 15,623

Year:
- 2005
- 2010
- 2015
- 2024

Emissions Trends for Pre/Post 2010: Korea

NEASPEC TAP Project Expert Consultation Meeting
Future Emission Change under Three Scenarios

Base-year  Future

Emissions

No Further Control (NFC)

Current Legislation (CLE)

Maximum Feasible Reduction (MFR)

Scenario

A : CLE (BAU)
B : AQ
C : MFR

Future Emission Change under Three Scenarios

PM\textsubscript{10}

SO\textsubscript{2}

NO\textsubscript{x}
Control Cost under Three Scenarios

### NOx

- **Scenario A**: CLE (BAU)
- **Scenario B**: AQ
- **Scenario C**: MFR

### PM$_{10}$

- **Scenario A**: CLE (BAU)
- **Scenario B**: AQ
- **Scenario C**: MFR

### SO2

- **Scenario A**: CLE (BAU)
- **Scenario B**: AQ
- **Scenario C**: MFR

**Scenario**

- **A**: CLE (BAU)
- **B**: AQ
- **C**: MFR
Future Health Loss under Different Scenarios

Life Loss (months)

BASE 2010

AQ 2030

CLE(BAU) 2030

MFR 2030

Future Health Loss under Different Scenarios

NEASPEC TAP Project Expert Consultation Meeting
Content

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2. An idea on a possible collaborative framework on TAP IAM in NE Asia
Understanding Regional Air Quality

1. Uncertainties of Emissions/Transport/Chemistry

   *Science and Technology*

2. Uncertainties of Emissions/Control/Contribution
Control Emissions and Control Future
: Seoul Air Quality Management Plan (SAQMP)

Seoul Metropolitan Area
Gyunggi
Incheon
Seoul

PM\(_{2.5}\) (new) PM\(_{10}\) NO\(_2\) O\(_3\) (new)

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<th>2024</th>
<th>2014</th>
<th>2010</th>
<th>2001</th>
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<tbody>
<tr>
<td>PM(_{2.5})</td>
<td>20μg/m(^3)</td>
<td>30μg/m(^3)</td>
<td>21ppb</td>
<td>60ppb</td>
</tr>
<tr>
<td>PM(_{10})</td>
<td>-</td>
<td>40μg/m(^3)</td>
<td>22ppb</td>
<td>-</td>
</tr>
<tr>
<td>NO(_2)</td>
<td>-</td>
<td>47μg/m(^3)</td>
<td>34ppb</td>
<td>-</td>
</tr>
<tr>
<td>O(_3) (new)</td>
<td>-</td>
<td>71μg/m(^3)</td>
<td>37ppb</td>
<td>-</td>
</tr>
</tbody>
</table>

The outline of SAQMP policy

Putting 8 billion dollars!
Air Quality Change on NE Asia

- NO2 (2005~2014)

NO2 Changes (%): 2005-2014

JAPAN
1 Tokyo (-38%)
2 Nagoya (-43%)
3 Osaka (-39%)
4 Fukuoka (-26%)
5 Nagasaki (NS)

YANGTZE RIVER DELTA
1 Shanghai (-30%)
2 Suzhou (11%)
3 Nanjing (15%)
4 Hangzhou (NS)

PEAK RIVER DELTA
1 Guangzhou (-44%)
2 Dongguan (-46%)
3 Shenzhen (-42%)
4 Hong Kong (-28%)

CHINA
Beijing (-10%)
Tianjin (21%)
Dalian (40%)
Shenyang (28%)
Qingdao (17%)
Wuhan (42%)
Xi'an (39%)
Fuzhou (12%)
Quanzhou (50%)
Taipei (29%)

TAIWAN

KOREA
Seoul (-15%)
Busan (NS)
New Challenge for Emissions and Air Quality: Winter Haze

Fine particle pollution over Seoul

2013, Dec 5th PM$_{10}$: 166 ug/m$^3$

2013, Dec 6th PM$_{10}$: 35 ug/m$^3$

Heavy pollution plume transport

NIER National Air Quality Forecasting (Nov. 2013)

PM$_{2.5}$ concentration in Beijing, Jan 2013

China

Korea

New Challenge for Emissions and Air Quality: Winter Haze
Overall, it is estimated that the NOx emissions are underestimated by 57.3% in North China and overestimated by 46.1% in South Korea over an entire year.

Some improvements except SO$_2$ over time, But still long way to go.
Uncertainties Emissions & Control

Emissions Inter-comparison

Update of emission factors and control measures for China

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Factors Affecting Emission Uncertainties
- “Not-well Known” Emissions (North Korea)
Impact of Regional NOx/VOC Control on O3 over Korea (Apr. 2009)

Removal Efficiency of NOx and VOC control measures in GAINS

- NOx only measures
- NOx “and” VOCs measures
- VOC only measures
An International Cooperative Air Quality Field Study
KORUS-AQ 2016 (1 May – 14 June)
**GEMS : Geostationary Environmental Monitoring Spectrometer**

![Image showing GEO and LEO positions](image)

<table>
<thead>
<tr>
<th>Satellite configuration w/payloads</th>
<th>2A</th>
<th>2B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>![Satellite Diagram]</td>
<td>![Satellite Diagram]</td>
</tr>
<tr>
<td>- 16 ch, Full size image &lt; 15 min</td>
<td>![ADI] Solar Panel</td>
<td>![GOCI-2] Solar Panel</td>
</tr>
<tr>
<td>- 0.5, 1 km (Vis), 2 km (IR)</td>
<td>![ADI] Solar Panel</td>
<td>![GOCI-2] Solar Panel</td>
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<tr>
<th>Life time</th>
<th>10 years</th>
<th>10 years</th>
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<tbody>
<tr>
<td>Launch Mass</td>
<td>2849 kg</td>
<td>2550 kg</td>
</tr>
<tr>
<td>Power</td>
<td>2903 W</td>
<td>2903 W</td>
</tr>
</tbody>
</table>
Understanding Regional Air Quality

1. Uncertainties of Emissions/Transport/Chemistry

Science and Technology

2. Uncertainties of Emissions/Control/Contribution

- Regional Collaboration beyond S & T

- From Understanding to Solution
Regional Collaboration beyond S & T

NEASPEC
(Integrated Future Strategy)

Policy Talk
(Control Measures)

Japan, China, S. Korea to cooperate on air pollution
May 6, 2013

LTP
(Transport and Chemistry)

Long-range Transport Project
GUIDE

(A solution maker…)

2020 and beyond
Integrated Management of Climate change and air quality

Window 1
Cost1
기후변화적응
Climate change Mitigation Policies

Window 3
Cost3
Integrated Policies (climate change and Local pollutants)

Window 2
Cost2
대기오염관리
Local Pollutant Mitigation policies

GHG (CO2, CH4, O3, N2O)

Other Pollutants (SO2, Nox, O3, VOCs, NH3, PM)

Ad.Impact 2 "Co_effect"
Impact 1
Impact of reduced GHG emissions

Impact 3
Impact of reduced GHG and LAP

Impact 2
Ad.Impact 1 "Co_effect"
Impact of reduced LAP (Local air pollutants)

GUIDE
## Integrated Assessment Model Development (International)

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<td>• IIASA</td>
<td>• GAINS</td>
<td>• No energy modeling</td>
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<tr>
<td></td>
<td></td>
<td>- Global</td>
<td>• Web-based service</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- China/Asia</td>
<td>• Source-receptor based transport</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Europe</td>
<td>• Optimization mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Italy</td>
<td>• Applied in many international negotiations</td>
</tr>
<tr>
<td>North America climate-air quality assessment (US EPA STAR Grant)</td>
<td>• US EPA + Berkeley/Columbia/NERL/GNM/Illinois/WSU/CMU</td>
<td>• CMAQ</td>
<td>• No emissions inventory</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• AQM</td>
<td>• Strong science-based</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• GEOS-Chem</td>
<td>• Climate-AQ interaction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• GISS</td>
<td>• 12 research consortium</td>
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<tr>
<td>ABaCAS: (Air Benefit and Cost and Attainment Assessment)</td>
<td>• US EPA-China</td>
<td>• CMAQ</td>
<td>• No climate change</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• SMAT</td>
<td>• Strong science and technology</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• RSM-VAT</td>
<td>• Real-time Source Apportionment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• BenMAP</td>
<td>• Applied for China</td>
</tr>
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• **Pros vs. Cons**
MESSAGE (IIASA) PAGE(Cambridge)
GCAM(PNNL)
AIM (NIES)

IPCC Assessment models

GUIDE*

Integrated CC-AQ assessment model
Integrated CC-AQ forecasting model

Integrated acid rain assessment model
Integrated AQ management model

* GHGs and Air pollutants Unified Information Design System for Environment(GUIDE)
Schematic Diagram of GUIDE system

Objective 1

- GHGs & AP Activity Control Policy & Technologies
- Cost, Health Impact
- GHGs and Aps Emissions Inventory System
- BC Emissions Inventory
- East Asia Emissions Inventory
- East Asia/Korea Meteorology Modeling
- Chemical Transport Modeling System
- Source-Receptor Response Surface
- Decision Support System for Integrated Management of GHGs and AP

Objective 2

- Energy & Activity DB
- Policy & Technology DB
- Cost DB
- Health Impact DB
- EF DB EM(Korea) DB EM(East Asia) DB

Objective 3

- User-oriented Service Interface

Decision Support System for Integrated Management of GHGs and AP
GUIDE

: a smart decision making system to manage GHGs and APs simultaneously

1) The new macro economy-based Benefit-Cost(B-C) model for decision making
2) State-of-science source-receptor surface that can assess impacts of emissions control in realtime, even for non-linear chemical reactions
3) Implementation of integrated GHGs and Air Pollutants(APs) emissions inventory for Korea
4) Incorporation of China and North Korea emission inventories to quantify out-of-region contribution
5) The simultaneous optimization for bi-directional co-control/co-benefits (i.e. co-benefits of APs and GHGs control)
Thank you for your attention!
Challenges and Opportunities
Supporting Filed Campaign and Improve Understanding of East Asia Emissions

Bottom-up

Emissions Estimation

Emissions Inventory

Emissions Processing

Emission Processor

Modeling Emissions Inventory

SMOKE-Asia/KU-EPS
(Woo et al., AE, 2009)

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**KORUS-AQ**

**Aircraft Field Campaign**

Airborne sampling
- provides critical view for evaluation strategies in connecting ground-based and satellite observations
- Short term

Satellites
- provide broad coverage, continuity
- but it needs reliable information on near-surface exposure.

**KORUS-AQ Goals**

- Improve capability for satellite remote sensing of air quality
- Better understanding of the factors controlling air quality
- Test and improve model simulation of air quality

**Ground monitoring**
- It will continue to be the primary method for monitoring exposure.
- Coverage is limited.

**Modeling**
- provide Air quality forecasting and warning service
- but it needs reliable information on emission inventory and so on.
Obstacles to Understand Regional Air Quality

1. Uncertainties of Emissions/Transport/Chemistry
2. Uncertainties of Emissions/Control/Contribution
Why Korea?

1. Korea’s urban/rural sectors are distinct, providing an attractive setting for understanding the relative importance of human and natural emissions.

2. The Korean peninsula and its surrounding waters provide an advantageous experimental setting for distinguishing local and trans-boundary pollution.

MODIS land cover map of South Korea.
Red colors-Urban & built up areas
Greens - forests, Gray - croplands
(courtesy Christine Wiedinmyer).
Asian NO\textsubscript{2} emissions from 1980 -2003 based on activity data (Ohara et al., 2007)

3. Korea is located in a region of rapid change with strong air quality gradients both in time and space.
   - PM\textsubscript{10} concentration of Seoul areas has been changed day by day
Why Korea?

4. Korea provides a collaborative environment with strengths in air quality monitoring and ground-based measurements, geostationary satellite observations, and modeling.
- over 300 regular air quality monitoring, 40 wet & dry deposition, 20 PAMS
- 6 supersite, 47 PM$_{2.5}$ mass & composition monitoring site

**DRAGON campaign (2012-2013)**
- It was a concentrated observation with ground-based sun photometers over megacities for detecting local emissions and over costal sites for detecting long range transport.

**Air Quality Forecasting**
- PM$_{10}$, PM$_{2.5}$ and Ozone
- 4 times/day
- Ensemble model results used
5. KORUS-AQ would build relationships and strengthen future collaboration critical to the success of the constellation of geostationary air quality satellites to be launched by NASA, NIER, and ESA later this decade.
Future AQ under Different Scenarios

PM$_{2.5}$ Conc. (ug/m$^3$)

BASE 2010

CLE(BAU) 2030

AQ 2030

MFR 2030
## Emissions Change for Year 2010

- Update of emissions factors and control measures for Korea

: Seoul Air Quality Management Plan (SAQMP)

### Source Regulations

<table>
<thead>
<tr>
<th>Source</th>
<th>Regulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Point Source</td>
<td>Total amount regulation and Emissions Trading</td>
</tr>
<tr>
<td></td>
<td>Expansion of areas using low-Sulfur fuel</td>
</tr>
<tr>
<td></td>
<td>Fuel switching, from Bituminous coal to LNG</td>
</tr>
<tr>
<td></td>
<td>Stricter Emission Allowance Standard</td>
</tr>
<tr>
<td></td>
<td>Agreement on voluntary environmental agreement</td>
</tr>
<tr>
<td></td>
<td>Training of Manuel for Best Facility Management</td>
</tr>
<tr>
<td></td>
<td>Financial support for facility investment</td>
</tr>
<tr>
<td></td>
<td>Stricter management of facility for PM10 &amp; VOC</td>
</tr>
<tr>
<td>Area Source</td>
<td>Expansion of district air conditioning and heating system</td>
</tr>
<tr>
<td></td>
<td>Expansion of small-scale Community Energy System</td>
</tr>
<tr>
<td></td>
<td>Expansion of Low-NOx boilers</td>
</tr>
<tr>
<td></td>
<td>Better management of LNG facilities</td>
</tr>
<tr>
<td></td>
<td>Eco- building standards and certification programs</td>
</tr>
<tr>
<td></td>
<td>Conversion of anthracite into natural gas</td>
</tr>
<tr>
<td></td>
<td>Expansion of areas using low-Sulfur and clean fuels</td>
</tr>
<tr>
<td></td>
<td>Regulation of fugitive dust in Industrial Process</td>
</tr>
<tr>
<td>Mobile Source</td>
<td>Stringent emission standards for new vehicles</td>
</tr>
<tr>
<td></td>
<td>Distribution of low emission vehicles</td>
</tr>
<tr>
<td></td>
<td>Emission reduction plan for specified-diesel-vehicles: SCR/DPF installation</td>
</tr>
<tr>
<td></td>
<td>Emission reduction plan for specified-diesel-vehicles: DOC installation</td>
</tr>
<tr>
<td></td>
<td>Higher quality standards for engine oil</td>
</tr>
<tr>
<td></td>
<td>Mandatory regular inspection program</td>
</tr>
<tr>
<td></td>
<td>Higher quality standards for gasoline fuels</td>
</tr>
<tr>
<td></td>
<td>Improvement of public transportation infrastructure</td>
</tr>
<tr>
<td>VOC Source</td>
<td>Stage II controls at gas stations</td>
</tr>
<tr>
<td></td>
<td>Restriction of the use of cutback asphalt</td>
</tr>
<tr>
<td></td>
<td>Restriction of solvent for consumer products</td>
</tr>
<tr>
<td></td>
<td>Emission Directive for paint in construction and</td>
</tr>
<tr>
<td></td>
<td>Expansion Installation</td>
</tr>
<tr>
<td></td>
<td>Installation of the application for Charbroiling restaurants</td>
</tr>
<tr>
<td></td>
<td>Clean Road</td>
</tr>
<tr>
<td></td>
<td>Expansion of low tire wear</td>
</tr>
<tr>
<td></td>
<td>Ground to Green Infra</td>
</tr>
</tbody>
</table>

### Summary

#### Target Air Quality

<table>
<thead>
<tr>
<th>Year</th>
<th>PM2.5</th>
<th>PM10</th>
<th>NO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>30㎍/㎥</td>
<td>34ppb</td>
<td>71㎍/㎥</td>
</tr>
<tr>
<td>2014</td>
<td>21ppb</td>
<td>30㎍/㎥</td>
<td>22ppb</td>
</tr>
</tbody>
</table>

#### BAU1

- 1st SAQMP
- 2nd SAQMP

#### Policies

- AISG, Konkuk University
- ABaCAS Workshop, December 2, 2015
- Source Regulations
- Total amount regulation and Emissions Trading
- Expansion of areas using low-Sulfur fuel
- Fuel switching, from Bituminous coal to LNG
- Stricter Emission Allowance Standard
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- Conversion of anthracite into natural gas
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- Stringent emission standards for new vehicles
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- Mandatory regular inspection program
- Higher quality standards for gasoline fuels
- Improvement of public transportation infrastructure
- Stage II controls at gas stations
- Restriction of the use of cutback asphalt
- Restriction of solvent for consumer products
- Emission Directive for paint in construction and
- Installation of the application for Charbroiling restaurants
- Clean Road
- Expansion of low tire wear
- Ground to Green Infra
### Emissions Change for Year 2010
- Update of emissions factors and control measures for China

#### Power Sector
- All coal-fired units shall install FGD, and the SO₂ removal efficiency increase to 90%.
- Coal-fired units except CFB boilers shall install denitration technologies.
- Upgrade the PM standard (from 50 mg/m³ to 30mg/m³), promote to use ESP + FGD or FAB.

#### Steel Industry
- Install desulfurization technologies on sintering operations.
- Upgrade the PM standard, promote to use high-efficiency dedusters (FAB).
- Eliminate outdated production capacity.

#### Industrial Boilers
- Coal-fired boilers greater than 20 t/h shall use desulfurization technologies.
- Upgrade the PM standard (50 mg/m³ for new boilers), promote to use ESP or FAB.
- New boilers should install LNB.
- Phase out small boilers.

#### Cement Industry
- Install LNB and denitration technologies in precalciner cement kilns.
- Upgrade the PM standard, promote to use high-efficiency dedusters (ESP or FAB).
- Eliminate outdated production capacity.

#### Industrial Kilns
- Upgrade de-dusting facilities.

#### Transportation
- Accelerate implementation of fuel and emission standards: implement Euro5 vehicle standards.
- Scrap the yellow-labeled and old vehicles.
- Promote to use new energy vehicles.

#### Key VOC industries
- Promote comprehensive treatment of VOCs in petrochemical industry and chemical industry.
- Promote leak detection and repair, online monitoring technology in the petrochemical, chemical and other key enterprises.
- Promote the use of water-based paint; encourage the production, sale and use of low toxicity, low volatile solvents.

#### Residential Sector
- Promote to use clean coal.
Emissions Evaluation over East Asia: China and Korea (2015)

China

Korea

NOx emissions (Mt)

NMVOC emissions (Mt)

Wang et al., ACP, 2014

NIER, 2014
The GAINS Models Family

- Korea
- MegaCity
- China
- Global
- Europe
- Italy
- Netherlands
- Ireland

Explore win-win strategies that simultaneously reduce air pollutant and greenhouse gases.

The GAINS model simulates the pathway of pollution from the sources to their multiple impacts. Its cost-effective optimization identifies policy measures that simultaneously improve air quality and reduce greenhouse gas emissions.

Specify your own economic development projection, and explore measures that achieve your air quality and greenhouse gas targets at least costs.
Air Quality Monitoring System for NIER/Korea

Air quality monitoring Stations: 350
  AQ : PM$_{10}$, O$_3$, NO$_2$, SO$_2$, CO
  Met : T, RH, winds
Roadside sites : 38
Rural sites : 19
Background sites : 3
VOCs sites: 31
Air Forecasting (Modeling) System for NIER/Korea

Today (Dec 2, 2015)

Tomorrow (Dec 2, 2015)
New Opportunities
: Geo-Satellite and Aircraft Field Campaign

Megacity Air Pollution Studies—Seoul
(MAPS—Seoul)

Lead Investigators:
Gwangwoong Lee (Hankuk University of Foreign Studies, HUPS)
Rohjae Park (Seoul National University, SNU)
Johon Kim (Yonsei University, YU)

Steering Committee at NIER:
You Doek Hong (Air Quality Research Division)
Joon Young Ahn (Air Quality Research Division)
Chang-Keun Song (Air Quality Forecasting Center)
Lima-Seok Chang (Air Quality Forecasting Center)
Jeong-Heu Park (Air Quality Forecasting Center)
Sang-Kyun Kim (Global Environment Research Division)
Jaidyun Lim (Global Environment Research Division)
Ji Young Kim (Air Pollution Engineering Division)

NIER
(National Institute of Environmental Research)
New Opportunity : Aircraft Field Campaign

1. NIER : Megacity Air Pollution Studies–Seoul (MAPS-Seoul)
   - 2nd SAQMP policy should be based on scientific evidences!

2. NASA : An International Cooperative Air Quality Field Study in Korea(KORUS-AQ)
   - Use of GEO satellites information to improve air quality forecasts, models, and strategies for mitigating poor air quality
KORUS-AQ
NASA DC-8

NASA Dryden Flight Research Center Photo Collection
http://www.cfrc.nasa.gov/gallery/photo/index.html
NASA Photo: E098-44444-7 Date: 25 Feb 1998 Photo by: Jim Ross
DC-8 Airborne Laboratory in flight over Mt. Whitney
Role of Emissions for Field Campaigns (Improve through Feedback)
MAPS-Seoul/KORUS-AQ Field Campaigns

\[ \text{CAE}_A = (\text{EF}_A) \cdot (Q) \cdot [1 - (\text{CE})(\text{RP})(\text{RE})] \]

AQ Forecasting Systems
- GEOS-Chem (SNU)
- WRF-Chem (PNU)
- CMAQ (GIST)
- CAMx (AJU)

0.5 degree gridded, monthly emissions for year 2010
27km gridded, hourly emissions for year 2010

Konkuk Univ
Summary

- A new regional emissions inventory, named NIER/KU-CREATE, was developed in support of various research/regulatory needs of Korea and East Asia.

- The on-going (MAPS-Seoul) and up-coming (KORUS-AQ) aircraft field campaigns could be a good chance to apply and improve the inventory. For this purpose, it has being served as the modeling emissions inventory for several Air Quality Forecasting System (AQFS), based on GEOS-Chem, CMAQ, WRF-Chem, CMAx.

- Initial MAPS-Seoul Campaign analysis revealed challenges and opportunities for the inventory and we are improving the information for upcoming field studies.
Social-Economic Condition

- Socio-economic scenarios are matched to SSP2, 3, 5
Social economic condition by scenario

Population: IIASA-WiC POP

GDP|PPP: OECD Env.-Growth

Source: IIASA
Social-Economic Parameter for China

Population: Peak near 2030

GDP growth Rates: Decreasing

Urbanization Rapid

Energy demand: Increasing
NIER/KU-CREATE: Control Tech (China) and Emissions (North Korea)

FGD Penetration

SO2 Emissions

S. Wang, 2012

AISG, Konkuk University

ABaCAS Workshop, December 2, 2015
## Social economic input data for MESSAGE

**ENERGY BALANCE OF CHINA -2010 (STANDARD QUANTITY)**

<table>
<thead>
<tr>
<th>Energy Total(coal equivalent calculation)</th>
<th>Energy Total(carbon value calculation)</th>
<th>Coal Total</th>
<th>Raw Coal</th>
<th>Cleaned Coal</th>
<th>Other Washed Coal</th>
<th>Briquettes</th>
<th>Gangue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Primary Energy Supply</td>
<td>332703.3744</td>
<td>224756.8375</td>
<td>226554.9418</td>
<td>-844.695</td>
<td>-948.017512</td>
<td>-3.39136</td>
<td></td>
</tr>
<tr>
<td>Indigenous Production</td>
<td>296915.7193</td>
<td>279693.7331</td>
<td>227319.7678</td>
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<td></td>
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<td></td>
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<tr>
<td>Hydro Power</td>
<td>23085.7104</td>
<td>8875.4938</td>
<td>227319.7678</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nuclear Power</td>
<td>23617.2585</td>
<td>907.9852</td>
<td>227319.7678</td>
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<td></td>
<td></td>
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<tr>
<td>Wind Power</td>
<td>3426.43382</td>
<td>548.40493</td>
<td>227319.7678</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery of Energy</td>
<td>5143.080619</td>
<td>5143.080619</td>
<td>227319.7678</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal Total</td>
<td>224756.8375</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Coal</td>
<td>224756.8375</td>
<td>226554.9418</td>
<td>227319.7678</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cleaned Coal</td>
<td>224756.8375</td>
<td>226554.9418</td>
<td>227319.7678</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other Washed Coal</td>
<td>-844.695</td>
<td>-948.017512</td>
<td></td>
<td>-3.39136</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Briquettes</td>
<td>-948.017512</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gangue</td>
<td>-3.39136</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Price of technology

<table>
<thead>
<tr>
<th>Technology</th>
<th>Investment cost(US$)</th>
<th>Fixed operation cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear</td>
<td>2000/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Hydro General</td>
<td>750/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Hydro Micro</td>
<td>2000/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Solar CSP</td>
<td>3500/kw</td>
<td>1.5%</td>
</tr>
<tr>
<td>Solar PV</td>
<td>3000/kw</td>
<td>0.5-1%</td>
</tr>
<tr>
<td>Wind Onshore</td>
<td>1300/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Wind Offshore</td>
<td>2400/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Biomass</td>
<td>1150/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Biogas</td>
<td>650/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Geothermal</td>
<td>1600/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Tidal</td>
<td>6500/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Fuel Cell</td>
<td>1000/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Coal Anthracite Steam</td>
<td>700/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Coal Bituminous Steam</td>
<td>700/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Coal Bituminous CCS</td>
<td>3000/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Heavy Oil</td>
<td>800/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>LNG Steam</td>
<td>550/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Combined Cycle</td>
<td>1500/kw</td>
<td>1-2%</td>
</tr>
<tr>
<td>Internal Combustion</td>
<td>1000/kw</td>
<td>1-2%</td>
</tr>
</tbody>
</table>

### Value Added in economic sectors (Unit: Billion Chinese yuan)

#### Primary (Agriculture, Mining, etc)
- 2010: 4053
- 2011: 4235
- 2012: 4419
- 2013: 4606
- 2014: 4795
- 2015: 4984
- 2016: 5148
- 2017: 5310
- 2018: 5467
- 2019: 5617
- 2020: 5759
- 2021: 5908

#### Secondary (Manufacturing)
- 2010: 18738
- 2011: 20165
- 2012: 21700
- 2013: 23352
- 2014: 25129
- 2015: 27040
- 2016: 28962
- 2017: 31021
- 2018: 33225
- 2019: 35585
- 2020: 38113
- 2021: 40365

#### Tertiary (Services)
- 2010: 17360
- 2011: 18964
- 2012: 20713
- 2013: 22621
- 2014: 24702
- 2015: 26971
- 2016: 29309
- 2017: 31846
- 2018: 34598
- 2019: 37584
- 2020: 40823
- 2021: 43928

### Monthly load cycle
Energy Projection by scenario

SSP2 (BAU)  SSP3 (Low)  SSP5 (High)

Unit: million TOE

Korean Society of Climate Change Research, August 13, 2015
AISG, Konkuk Univ.
National action plan and emission standard for China

By 2017, the government aims to reduce the PM$_{2.5}$ concentration by 25%, 20% and 15% in BTH, YRD and PRD.

http://kjs.mep.gov.cn/hjbhbz/bzwb/
Implementation of Control technology

SO2

NOx

PM2.5

VOC

AISG, Konkuk Univ.
Korean Society of Climate Change Research, August 13, 2015
Future Projection of emission by scenario

Gg/yr
배출저감과 대기환경개선

Korea (Seoul)

China (Power Plants)
Multiplatform Observation of Air Quality in Korea :

An International Cooperative Air Quality Field Study

KORUS-AQ 2016 (1 May – 14 June)
Korea AQ Policy: Seoul Air Quality Management Plan (SAQMP)

The outline of SAQMP policy

<table>
<thead>
<tr>
<th>Year</th>
<th>PM$_{2.5}$</th>
<th>PM$_{10}$</th>
<th>NO$_2$</th>
<th>O$_3$(new)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2024</td>
<td>20 µg/m$^3$</td>
<td>30 µg/m$^3$</td>
<td>21 ppb</td>
<td>60 ppb</td>
</tr>
<tr>
<td>2014</td>
<td>-</td>
<td>40 µg/m$^3$</td>
<td>22 ppb</td>
<td>-</td>
</tr>
<tr>
<td>2010</td>
<td>-</td>
<td>47 µg/m$^3$</td>
<td>34 ppb</td>
<td>-</td>
</tr>
<tr>
<td>2001</td>
<td>-</td>
<td>71 µg/m$^3$</td>
<td>37 ppb</td>
<td>-</td>
</tr>
</tbody>
</table>
Society, Energy, Emissions and Future in terms of Air Quality and Climate Change

- Global climate change potentially impacts regional air quality
- Future Climate Change (CC) and Air Quality (AQ) should be understood together,
  
  require understandings of
  - Present CC & AQ status : f(Emissions, Meteorology, Reaction, …)
  - Future changes : f(growth, control)
    growth : f(socio-economic par., energy pathways, …)
    control : f(policy, technology, economy, …)

Result : Shortest-term (Daily Chemical Weather Forecasting)
          Mid-term (Decadal Prediction for Policy Analysis)
          Long-term (Half/full Century Prediction for CC-AQ Works)

- Present status and future research efforts of Korea
  
  *(an overview based on my viewpoint)*