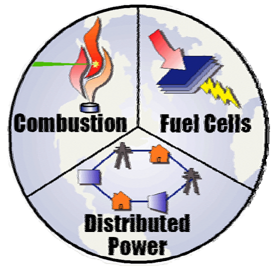
Urban Air Quality Impacts of Distributed Generation
in the South Coast Air Basin



Donald Dabdub, Jack Brouwer, G. Scott Samuelsen
Marc Medrano, Marco Rodriguez, Marc Carreras

Advanced Power and Energy Program
Computational Environmental Sciences Laboratory
University of California, Irvine

September 27, 2004

Outline

- Project Overview
- Development of DG Implementation Scenarios
- Air Quality Model Overview
- Distributed Generation Air Quality Simulation Results

Project Overview

Project Goals

- Construct a set of likely distributed generation implementation scenarios,
- Evaluate a set of scenarios for determining the impact of DG in the South Coast Air Basin,
- Verify that accurate accounting of aerosol dynamics is required for air quality modeling of the South Coast Air Basin,
- Determine whether the accuracy of state-of-the-art air quality models is sufficient to capture impacts of DG,

Project Overview

Project Goals (cont.)

- Compare model predictions and conclusions to ARB simulations for the South Coast Air Basin,
- Coordinate modeling activities to assure consistent predictions with the South Coast Air Quality Management District and California Air Resources Board, and
- Coordinate with and support the Central California Ozone Study (CCOS) through provision of results, modules, scenarios, and technical advise as desired or required.

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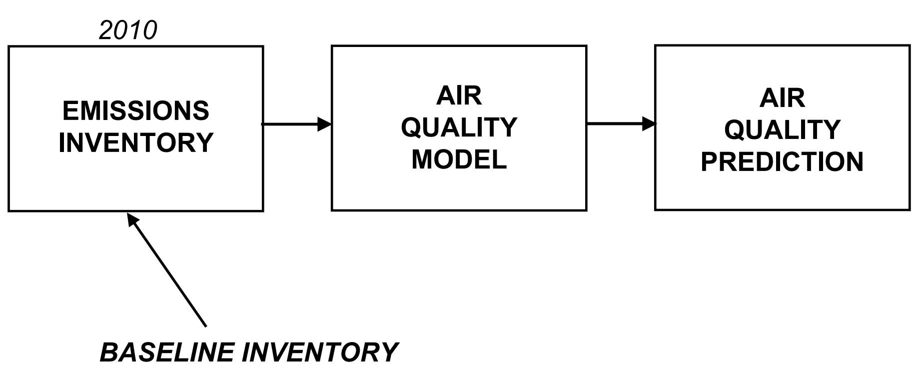
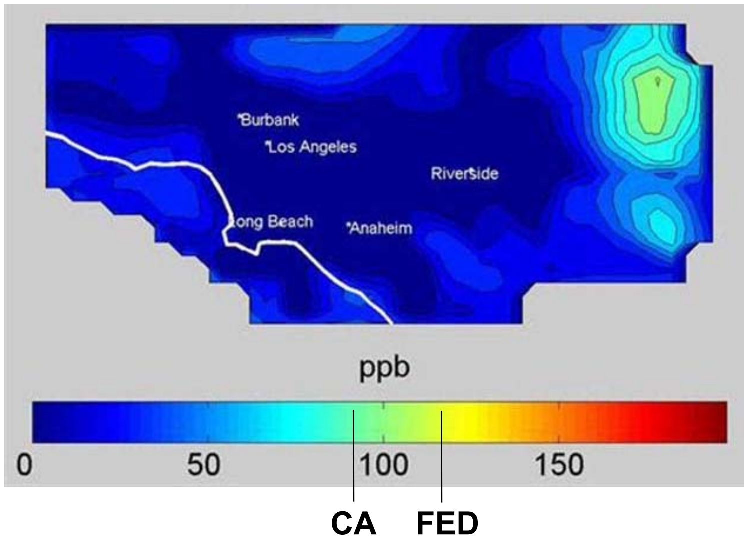
Project Overview

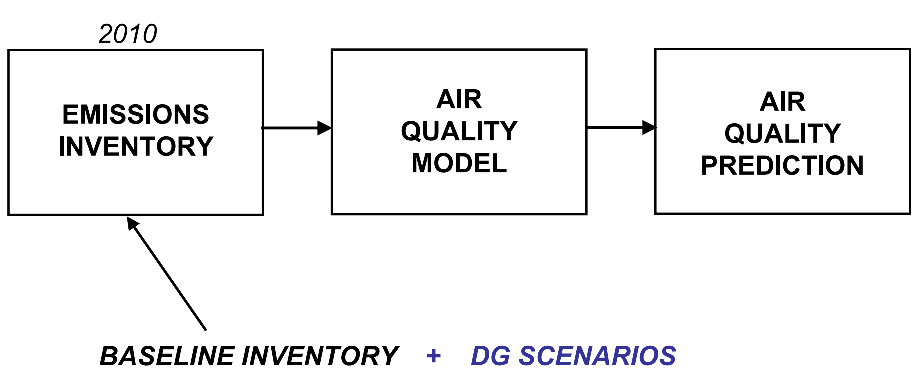
- South Coast Air Basin (SoCAB)
- Focused on the year 2010
  - Considering other years and future DG potential and impacts
- Major current & emerging distributed generators considered
  - MTGs, Fuel Cells, ICEs, Solar, Wind, etc.
- Builds upon previous expertise and efforts at UCI
  - Distributed Generation
  - Air Quality Simulation
- Two Industry Stakeholder Workshops (9/19/02, 5/21/03)
- Agency oversight and guidance
  - California Energy Commission (CEC)
  - California Air Resources Board (ARB)
  - South Coast Air Quality Management District (AQMD)



South Coast Air Basin in 2010

O_3 at 01:00 (without DG)





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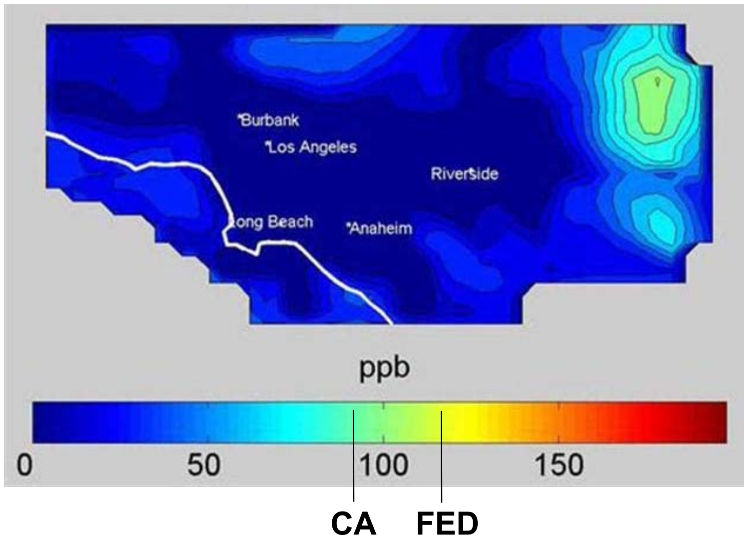
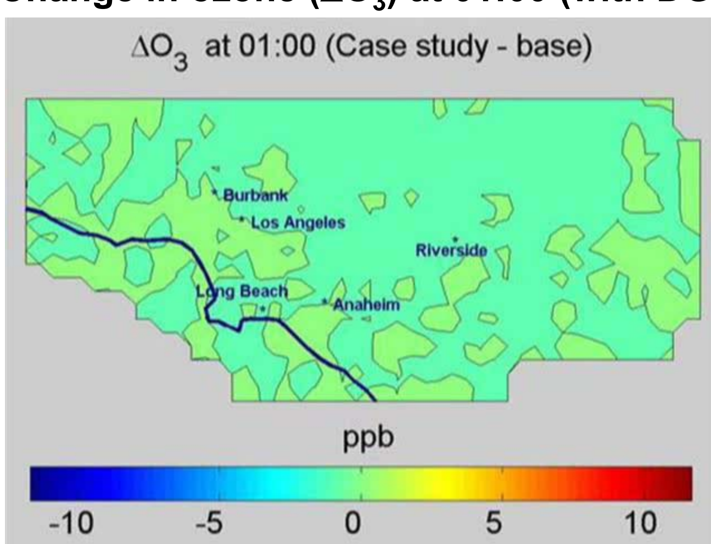
South Coast Air Basin in 2010

O_3 at 01:00 (with DG)



South Coast Air Basin in 2010

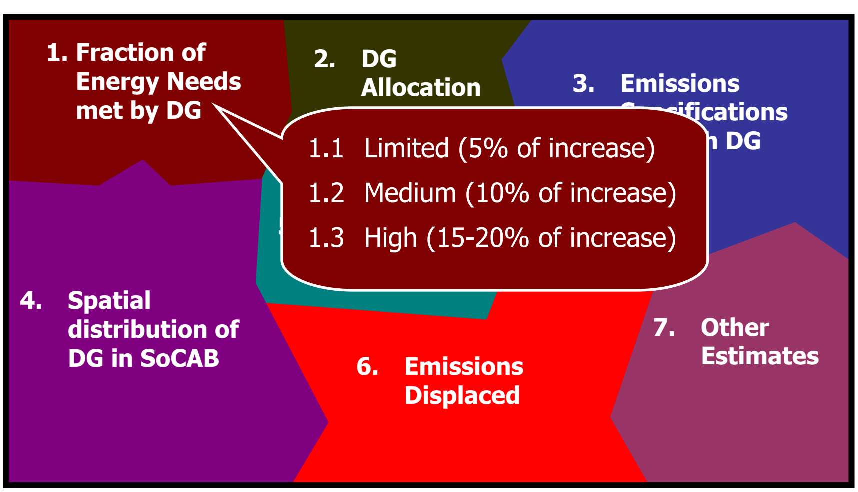
Change in ozone (ΔO_3) at 01:00 (with DG)



Outline

- Project Overview
- **Development of DG Implementation Scenarios**
- Air Quality Model Overview
- Distributed Generation Air Quality Simulation Results

DG Scenario Parameters



DG Scenario Parameters

1. Fraction of Energy Needs met by DG

2. DG Allocation

3. Emissions Specifications for each DG

2.1 Types of DG units
- 2.1.1 All NG large GT-DG (50 MW)
- 2.1.2 Fuel Cell Only
- 2.1.3 MTG only
- 2.1.4 Renewables – yes, no
- 2.1.5 Mix of DG (MTG, FC, NG-ICE, Stirling, hybrid, …)
- 2.1.6 Mix of DG and large GT-DG (50 MW)
- 2.1.7 Diesel included – yes or no

DG Scenario Parameters

1. Fraction of Energy Needs met by DG

2. DG Allocation

3. Emissions Specifications for each DG

4. Spati distri DG i

2.2 Number of DG units of each type
- 2.2.1 Large DG unit size vs. small DG unit size
- 2.2.2 Mix Factors
  - 2.2.2.1 High penetration of low emissions technologies (strong regulation/policy drivers)
  - 2.2.2.2. Low penetration of low emissions technologies (modest regulation or lack of technology advancement)
  - 2.2.2.3 Zoning or land-use
- 2.2.3 Economic factors (e.g., DUA study)

Resources to Base DG Power with Land-use

- California Electricity Consumption by Sector
- "A Look at Residential Energy Consumption in 1997, EIA, 1999"
- Electricity Consumption Intensities
  - Electricity Consumptions
  - Land use areas

Resources to Base DG Power with Land-use

- DG Market penetration studies in different economic sectors
  - Utility sector (Source: " Air Pollution Emissions Impacts Associated with the Economic Market Potential of Distributed Generation in California", Ianucci et al., 2000)
  - Building sector (Residential + Commercial) (source: "Modeling Distributed Generation in the NEMS building models", Boedecker et al, 2000)
  - Industrial sector (Source: "Opportunities for Micropower and Fuel Cell Gas Turbine Hybrid Systems in Industrial Applications", Jan 2000, A.D. Little)
- Educated estimates for the DG mix in the rest of the sectors where data is not available

DG Scenario Parameters

1. Fraction of Energy Needs met by DG

2. DG Allocation

3. Emissions Specifications for each DG

- 3.1 Current emissions factors
  - 3.1.1 Known emissions factors – literature, data
  - 3.1.2 Estimated emissions factors
- 3.2 Future advancements to meet regulatory requirements
  - 3.2.1 Fraction that meets 2003 standards
  - 3.2.2 Fraction that meets 2007 standards

er
imates

DG Scenario Parameters

1. Fraction of Energy Needs met by DG

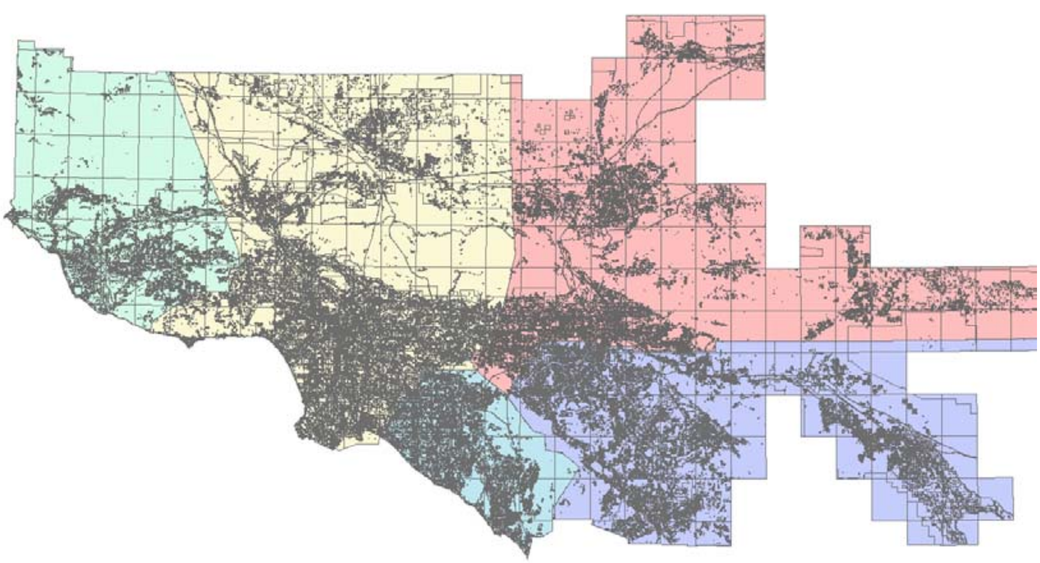
4. Spatial distribution of DG in SoCAB

- 4.1. Even
- 4.2 Population weighted
- 4.3 Population growth weighted
- 4.4 Land-use weighted
  - 4.4.1 Classify Land-use
  - 4.4.2 Land use energy adoption rate factors
  - 4.4.3 Land-use weighted technology adoption factors
- 4.5 Electrical use weighted (if available from SCE/LADWP)
- 4.6 Freeway weighted

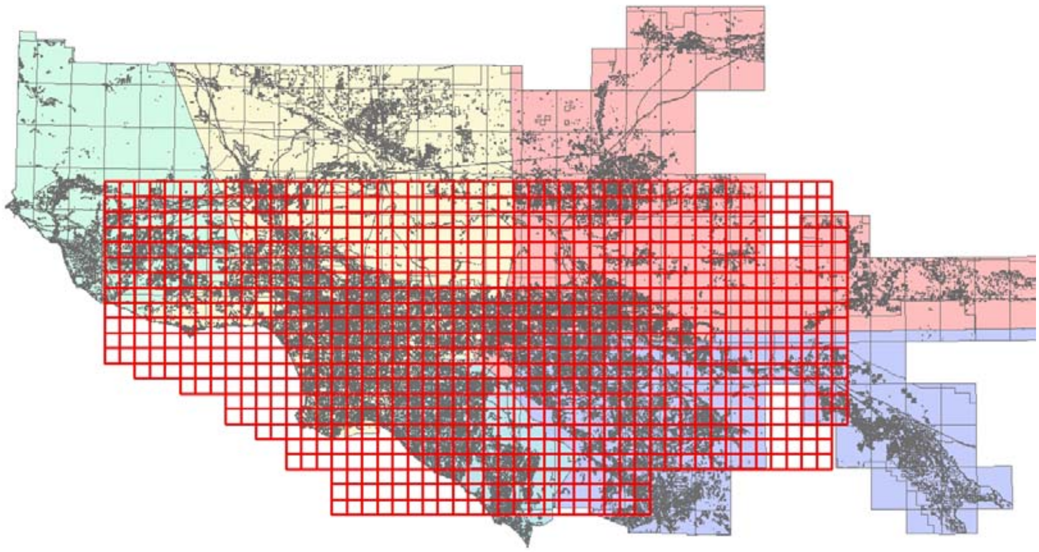
GIS Land-use Data Description

- GIS land-use data of 6 counties: Los Angeles, Orange, Riverside, San Bernardino, Imperial and Ventura
- Donated by the Southern California Association of Governments (SCAG) on Nov 15, 2002
- More than 100,000 land parcels in SoCAB, describing 132 specific land-use types and 13 generic types [two acre (0.0081 km^2) resolution]
- Challenging work to compile all parcels in the 5 km x 5 km air quality model format

Available GIS Land-use Information

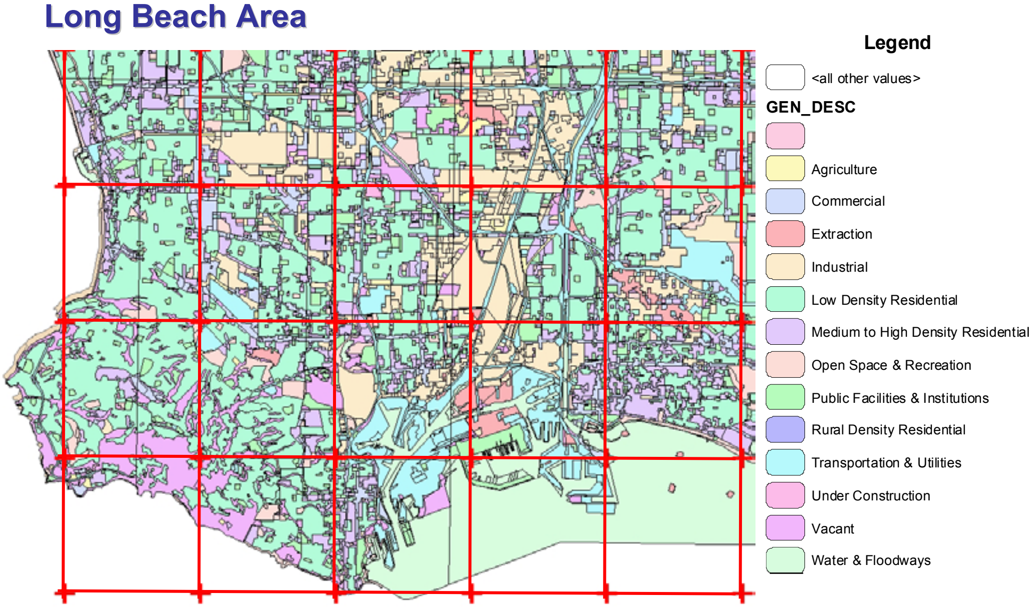


GIS Land-Use Data



GIS Land-Use Data

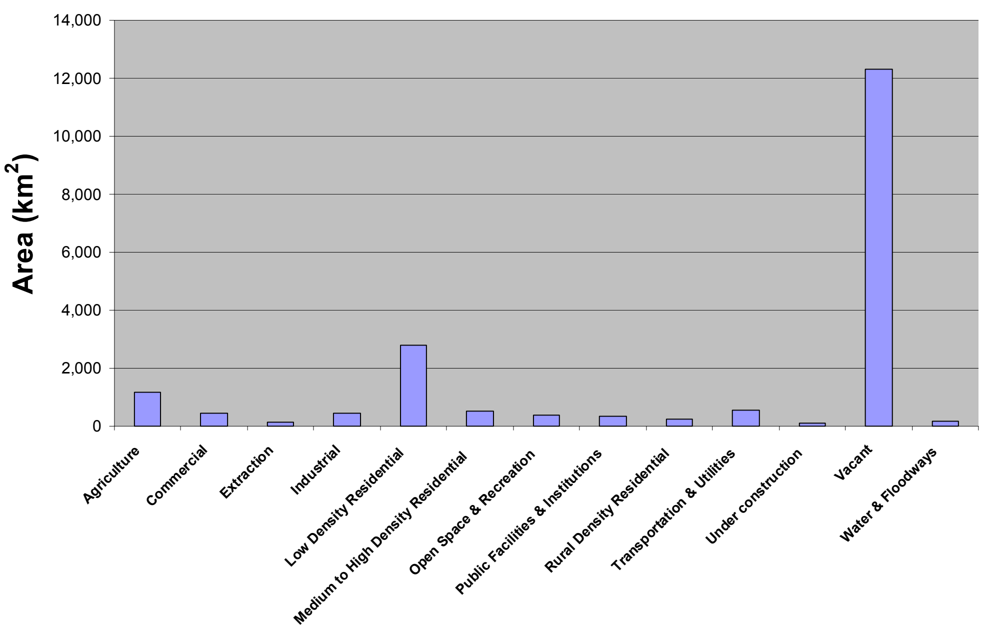
Long Beach Area



Land-use Categories Extracted

1. Agriculture
2. Commercial
3. Extraction
4. Industrial
5. Low Density Residential
6. Medium to High Density Residential
7. Open Space and Recreation
8. Public Facilities and Institutions
9. Rural Density Residential
10. Transportation and Utilities
11. Under Construction
12. Vacant
13. Water and Floodways

Total Area for Each Land-use Type



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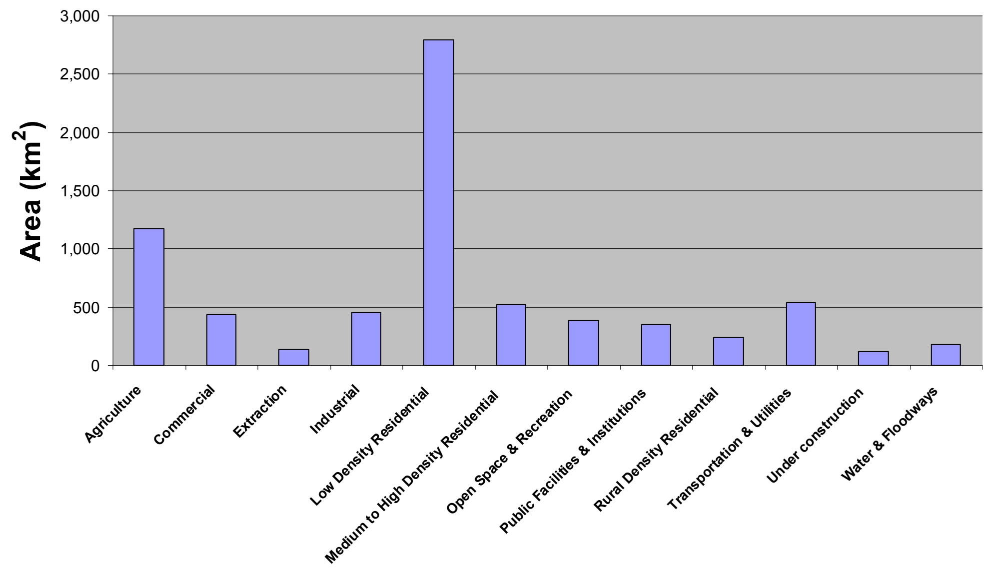
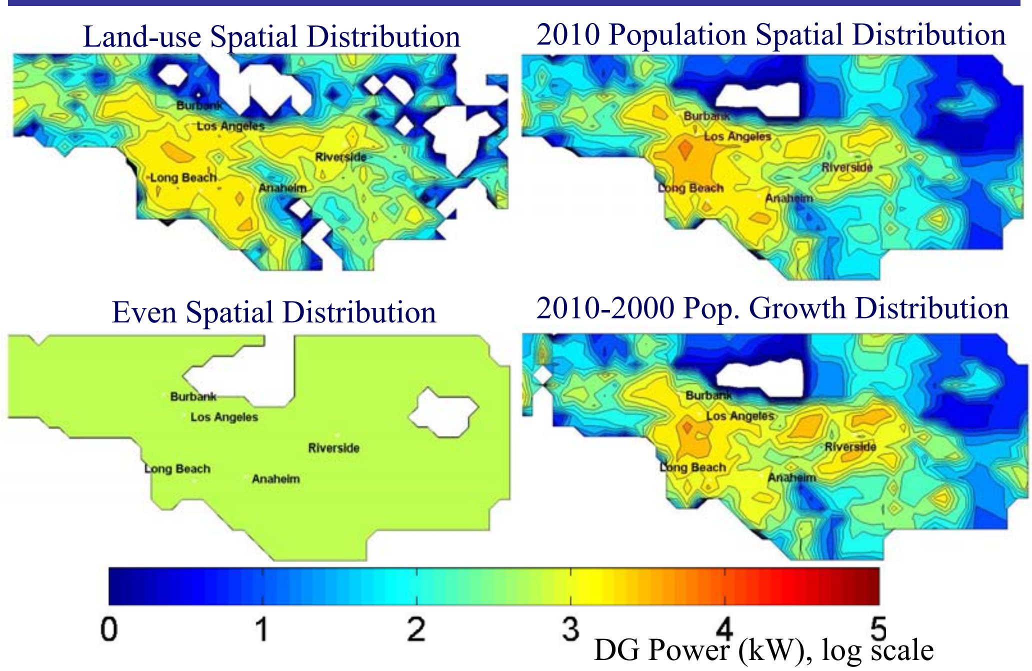
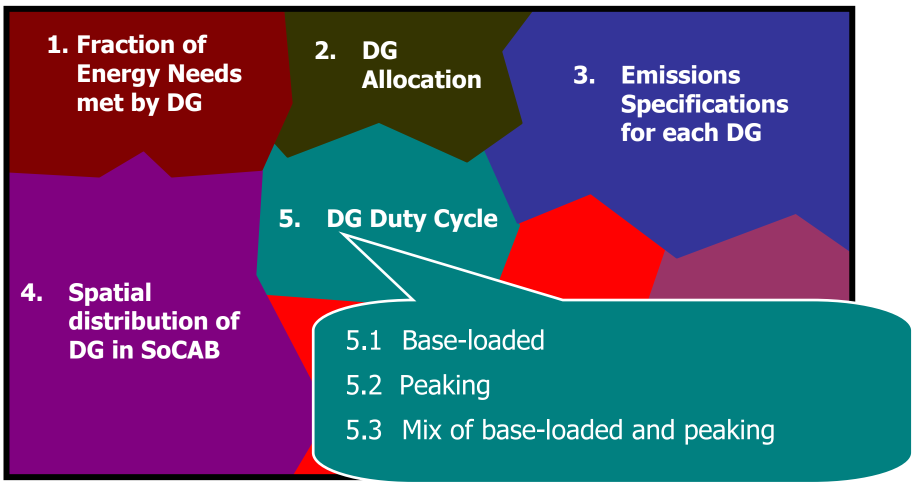
Total Land-use Area (“Vacant” Type Removed)



DG Power (~0.5 GW) Spatial Distributions

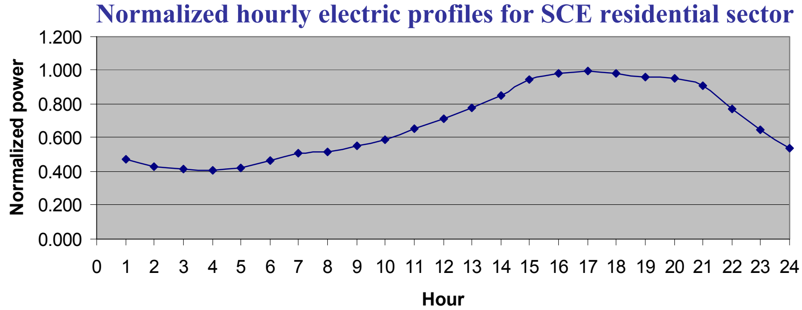


DG Scenario Parameters

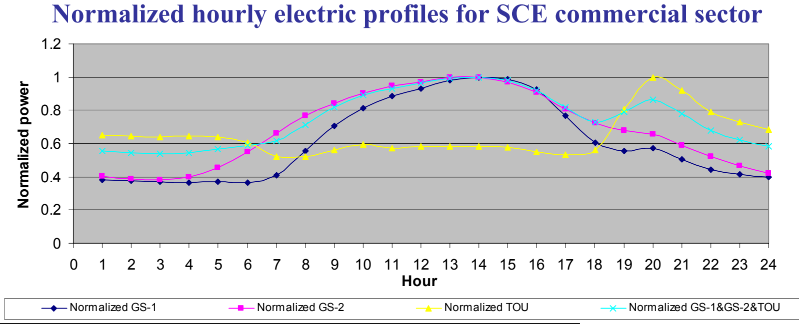


Updated Realistic Approach with Duty Cycle

Normalized hourly electric profiles for SCE residential sector

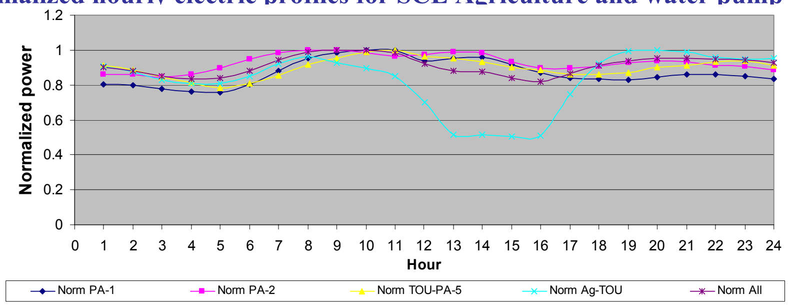


Normalized hourly electric profiles for SCE commercial sector

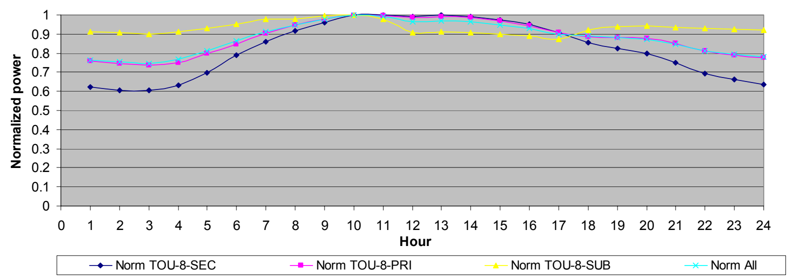


Updated Realistic Approach with Duty Cycle

Normalized hourly electric profiles for SCE Agriculture and water pump sector



Normalized hourly electric profiles for SCE industrial sector



DG Scenario Parameters

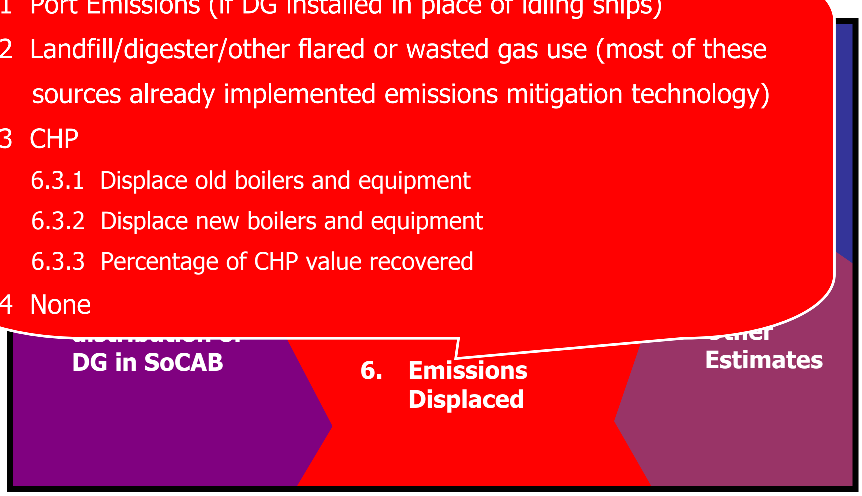
6.1 Port Emissions (if DG installed in place of idling ships)

6.2 Landfill/digester/other flared or wasted gas use (most of these sources already implemented emissions mitigation technology)

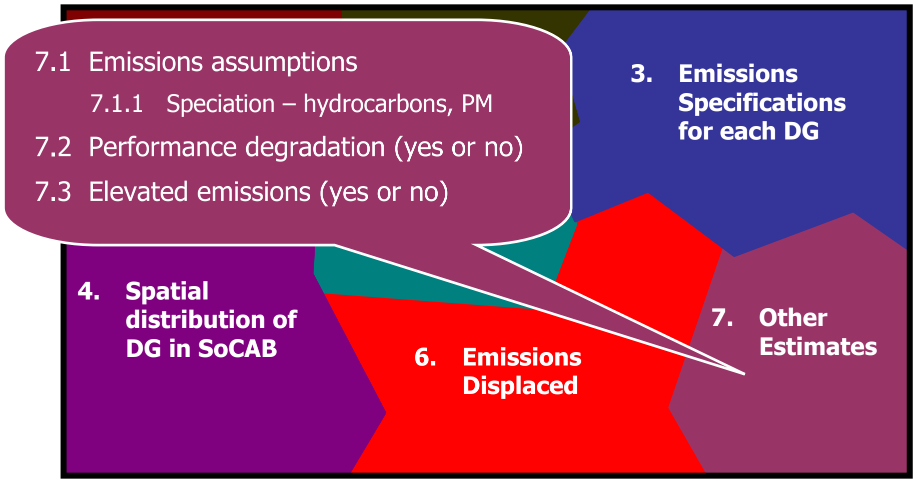
6.3 CHP

- 6.3.1 Displace old boilers and equipment
- 6.3.2 Displace new boilers and equipment
- 6.3.3 Percentage of CHP value recovered

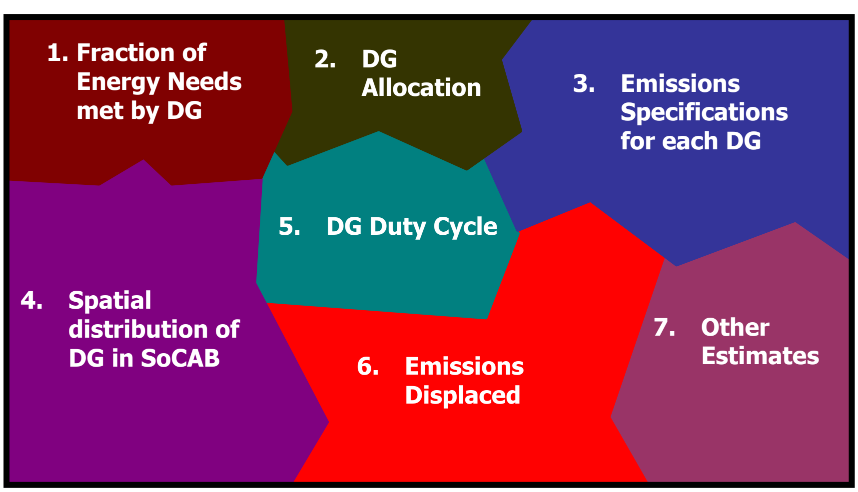
6.4 None



DG Scenario Parameters



DG Scenario Parameters



DG Scenario Screening

- **All possible permutations of parameters and factors: 39! (2.04×10^{46}) scenarios**

- **Screen scenarios into two groups**

  1. **"Realistic DG Implementation Scenarios"**
     - **Likely to be implemented**

  2. **"Spanning DG Implementation Scenarios"**
     - **For scientific completeness**
     - **For sensitivity analysis**
     - **Determination of potential impacts for unexpected outcomes**

DG Scenarios Summary

5 Realistic Scenarios:

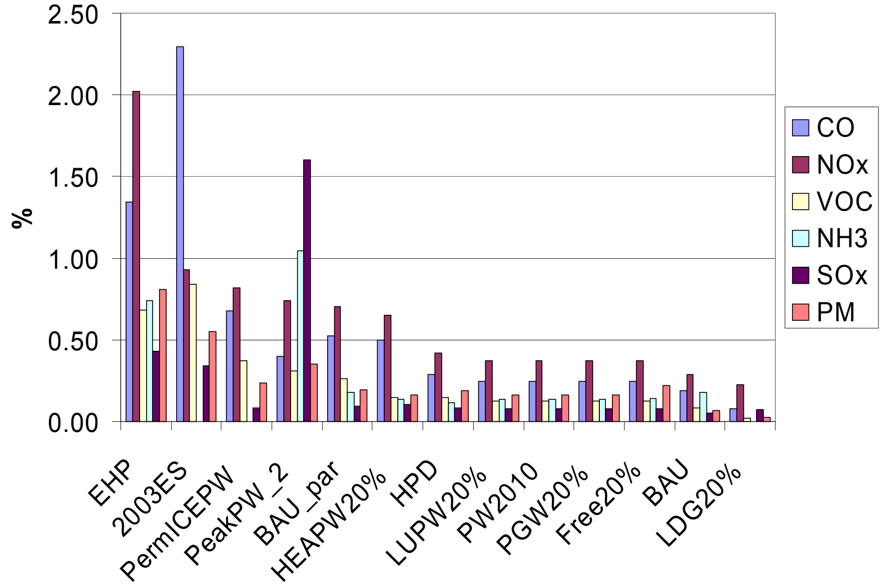
– **GIS Land-use spatial distribution for each DG technology**
– **Duty cycle typical for each activity sector**
– **CHP Emission displacement: yes/no**
– **DG penetration: 5, 10, 20% of increased power demand from 2002 to 2010**
– **DG Adoption Rate: Low early adoption/medium early adoption**

21 Spanning Scenarios:

– **Spatial distribution: Population, Population growth, Land-use, freeways**
– **Duty cycle: DG base-loaded/6-hour duty cycle**
– **DG penetration: 20% of increased power demand, 20% of total power demand in 2010**
– **Technology mix: only MTG, ICE, GT, FC, mix of DG**

Emissions from DG (1/2)

Daily emissions from DG as a percentage of baseline emissions



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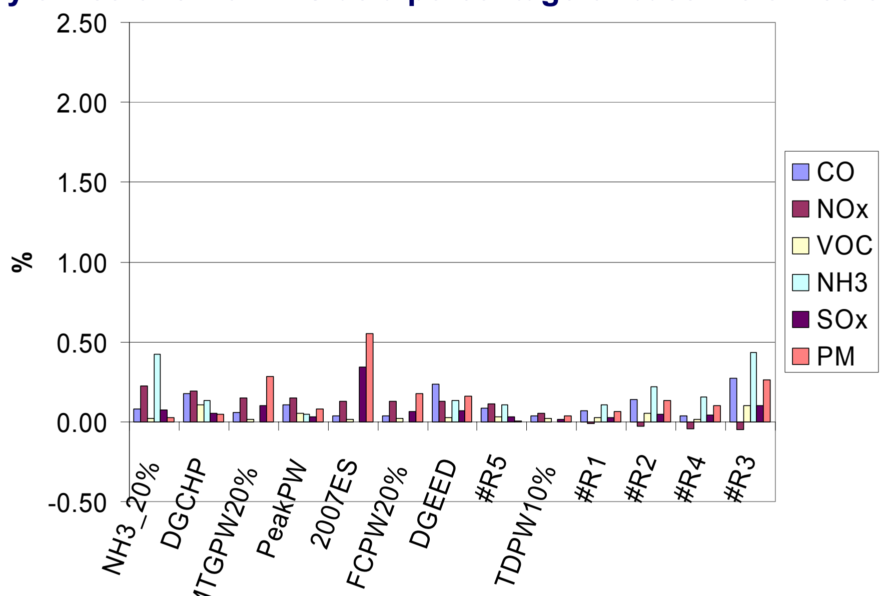
Emissions from DG (2/2)

Daily emissions from DG as a percentage of baseline emissions



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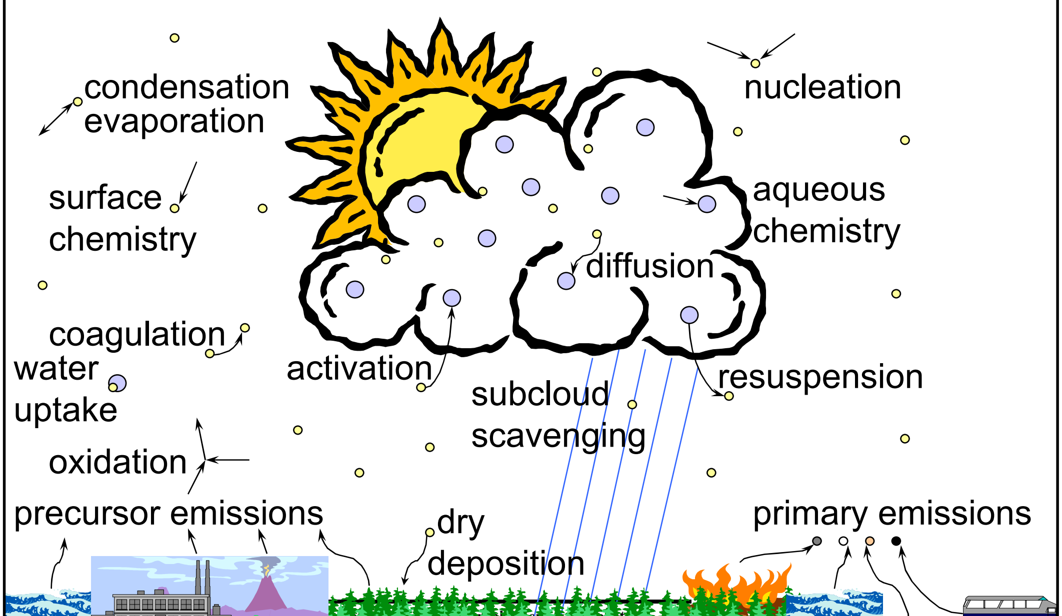
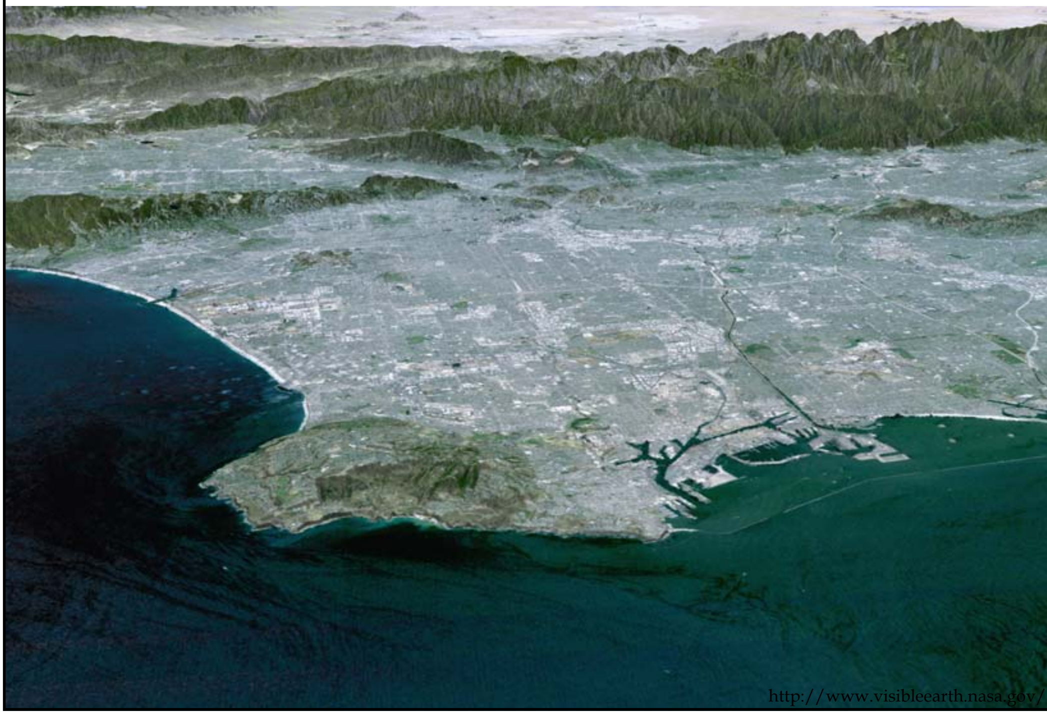
Outline

- Project Overview
- Development of DG Implementation Scenarios
- **Air Quality Model Overview**
- Distributed Generation Air Quality Simulation Results



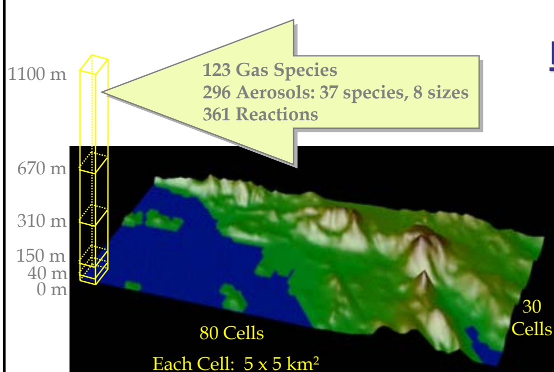
South Coast Air Basin of California



The Air Quality Model - CIT Airshed Model

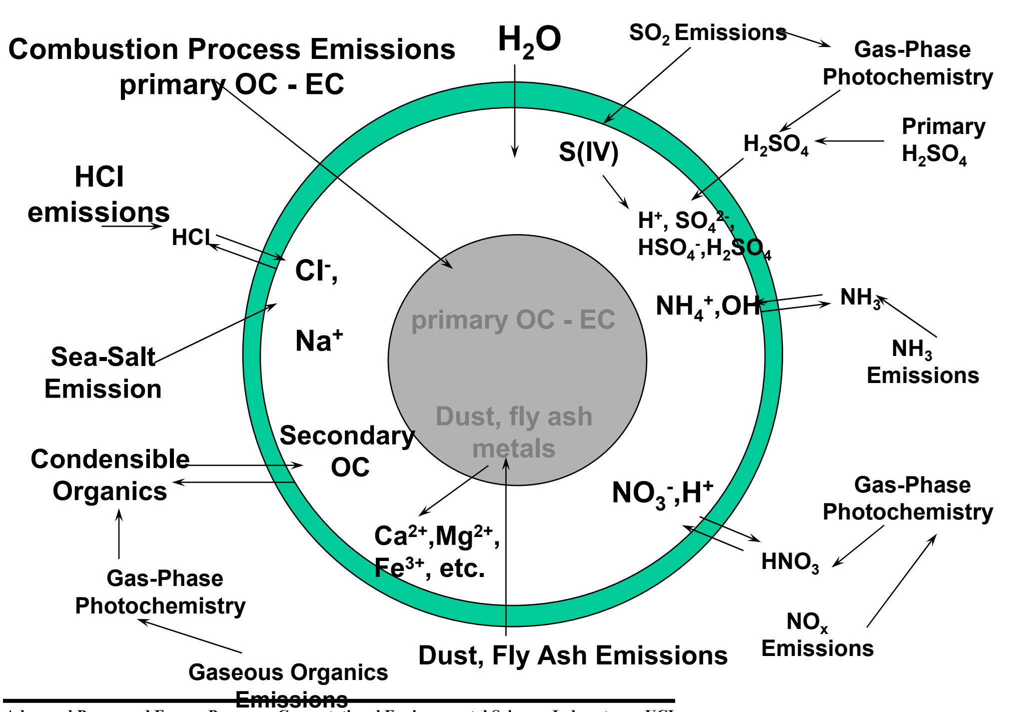
Governing Dynamic Equation:

$$\frac{\partial Q_m^k}{\partial t} + \nabla\cdot\left(uQ_m^k\right) = \nabla\cdot\left(K\nabla Q_m^k\right) + \left(\frac{\partial Q_m^k}{\partial t}\right)_{sources/sinks} + \left(\frac{\partial Q_m^k}{\partial t}\right)_{aerosol} + \left(\frac{\partial Q_m^k}{\partial t}\right)_{chemistry}$$



Meteorological Conditions:

- Measurements from Southern California Air Quality Study (SCAQS), Sept. 27-29, 1987
- High Ozone concentration episode due to strong thermal inversion and wind circulation



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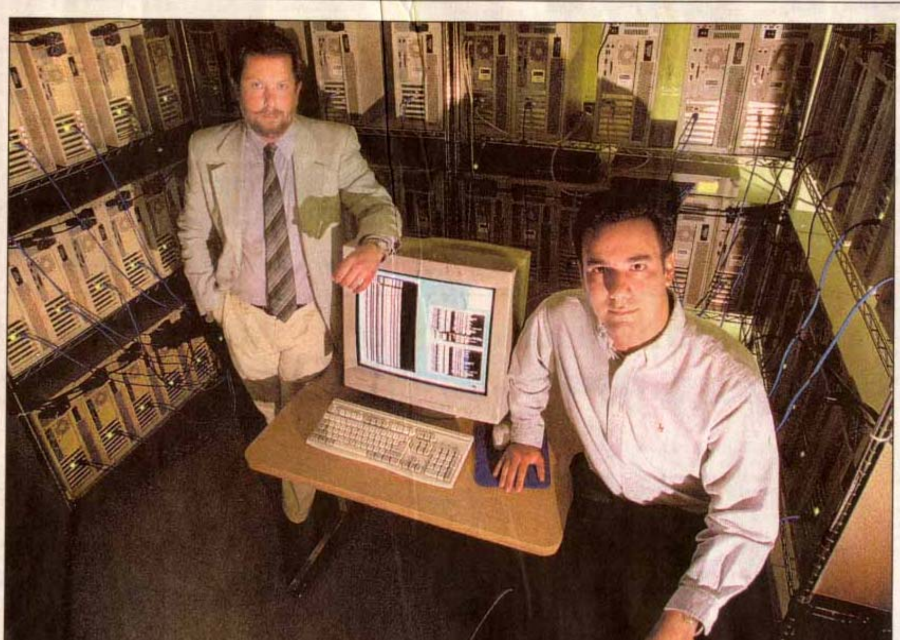
MONDAY
AUGUST 24, 1998

THE CUTTING EDGE



UC Irvine professors Herbert Hamber, left, and Donald Dabdub use the Linux operating system to link their computers to create a

Outline

- Project Overview
- Development of DG Implementation Scenarios
- Air Quality Model Overview
- **Distributed Generation Air Quality Simulation Results**

Base Case Simulation Results (1/3)

Maximum hourly-averaged concentration for species Base case: year 2010

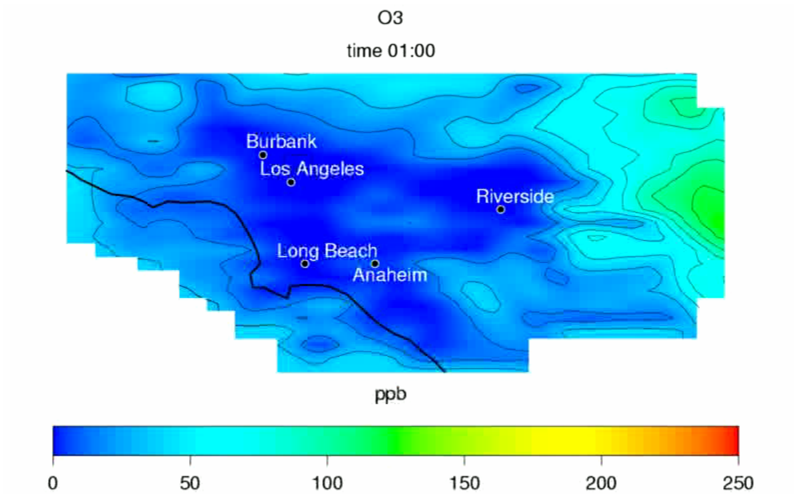
Species	Maximum	Location	Time
O_3	238 ppb	San Bernardino	13:00
NO_2	158 ppb	Riverside	05:00
CO	3 ppm	Los Angeles	06:00
$PM_{2.5}$	115 $\mu g/m^3$	Riverside	N/A
PM_{10}	163 $\mu g/m^3$	Los Angeles	N/A

Current Ambient Air Quality Standards for California

Species	State Standard	Averaging time
O_3	90 ppb	1 hr
NO_2	250 ppb	1 hr
CO	9 / 20 ppm	8 hr / 1 hr
$PM_{2.5}$	65 $\mu g/m^3$	24 hr
PM_{10}	50 $\mu g/m^3$	24 hr

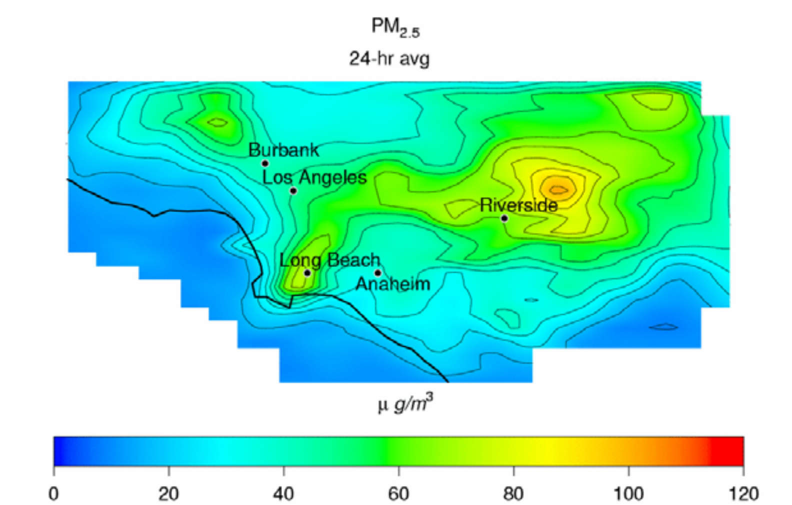
Base Case Simulation Results (2/3)

Daily variation of hourly-averaged ozone concentration



Base Case Simulation Results (3/3)

24-hour average $PM_{2.5}$ concentration

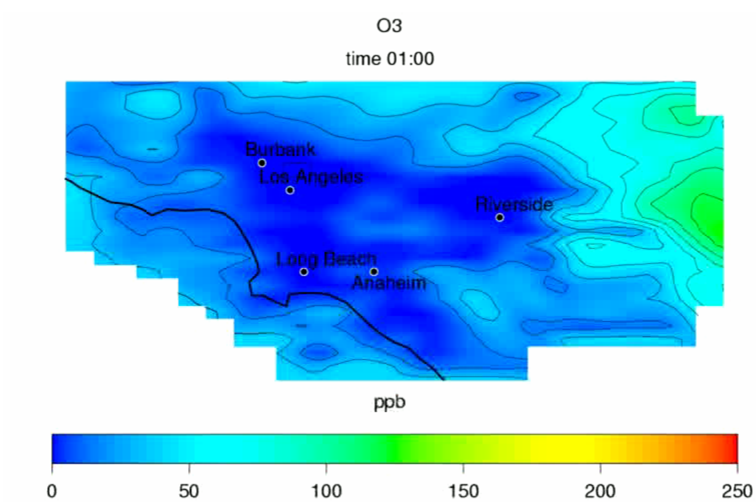


Realistic Scenarios Summary

DG Scenario	Parameters that describe each scenario
#R1	• 5% of increased power demand from 2002 to 2010 met by DG • Technology mix according to activity sector distribution • High penetration of low emission technologies • Spatial distribution according to GIS land use distribution • Realistic duty cycle per each sector • CHP emission displaced • Low performance degradation (3% increase of emissions per year) • Linear trend for DG power adoption (Medium early adoption of DG Power)
#R2	• 10% of increased power demand from 2002 to 2010 met by DG • Same assumptions as in #R1 for the rest of parameters
#R3	• 20% of increased power demand from 2002 to 2010 met by DG • Same assumptions as in #R1 for the rest of parameters
#R4	• Low early adoption of DG Power (98% of DG installed in 2007 or after) • Same assumptions as in #R1 for the rest of parameters
#R5	• No CHP emissions displaced • Same assumptions as in #R1 for the rest of parameters

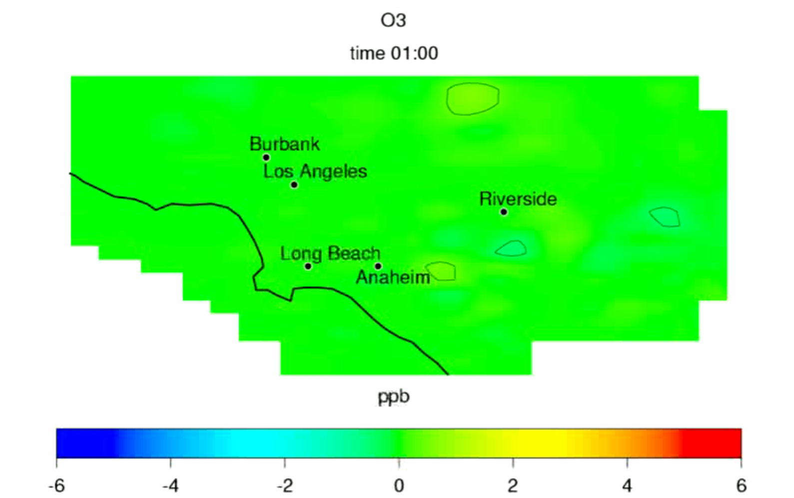
Realistic Scenario #1

Ozone hourly variation: Realistic #1



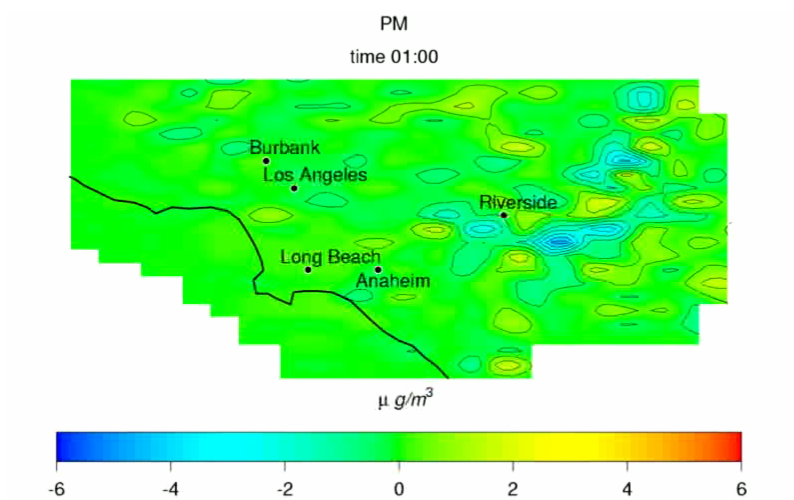
Realistic Scenario #1

Hourly ozone difference (ΔO_3): Realistic #1 – Base case



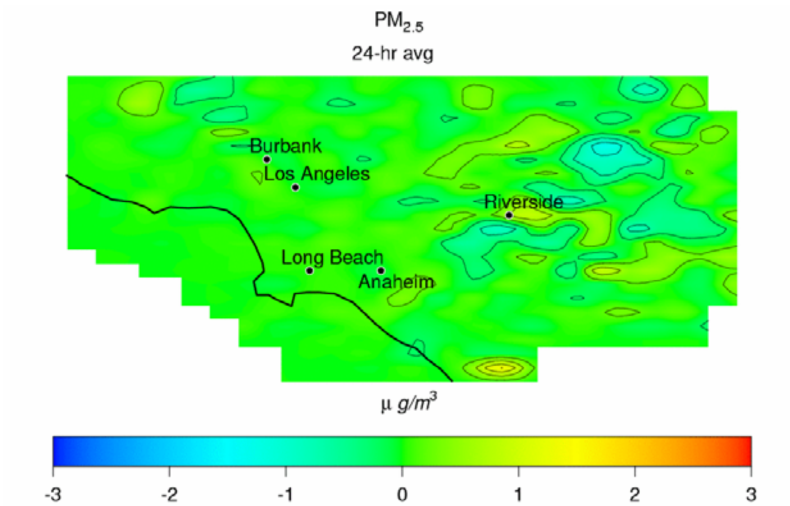
Realistic Scenario #1

Hourly $PM_{2.5}$ concentration difference ($\Delta PM_{2.5}$): Realistic #1 – Base case



Realistic Scenario #1

$PM_{2.5}$ 24-hour average difference ($\Delta PM_{2.5}$): Realistic #1 – Base case



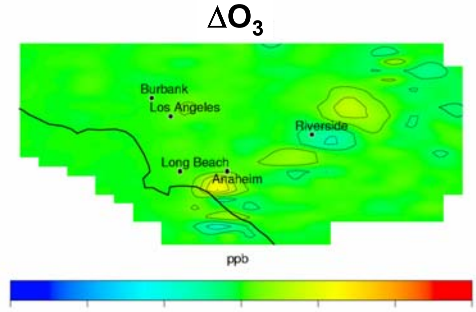
Air Quality Impacts of DG Scenarios – 'Realistic'

Realistic scenarios:

- Basin-wide emission increases due to DG are less than 0.5%
- #R1: impact on ozone and $PM_{2.5}$ concentration is very small

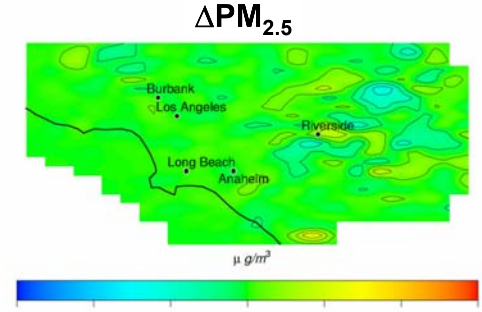
O_3 at hour 13

ΔO_3



24-hour average $PM_{2.5}$

$\Delta PM_{2.5}$



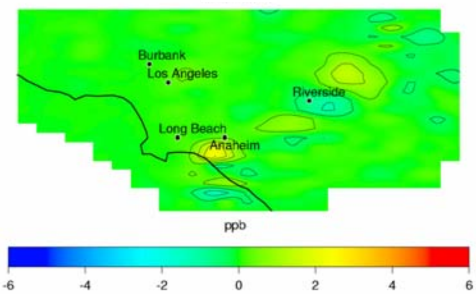
Air Quality Impacts of DG Scenarios – 'Realistic'

Realistic scenarios:

- Increasing DG market penetration from 5% to 20% of the increased electricity demand from 2002 to 2010 leads to slightly higher impacts on ozone and $PM_{2.5}$ concentration

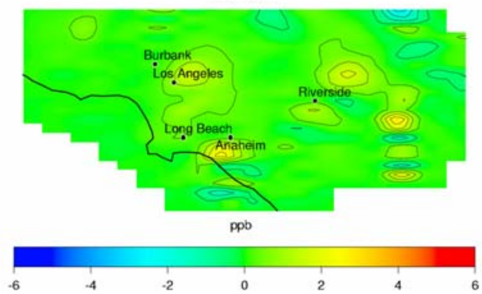
5% of increased demand (#R1)

ΔO_3



20% of increased demand (#R3)

ΔO_3

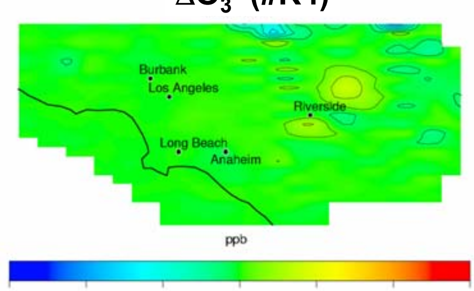


Air Quality Impacts of DG Scenarios – 'Realistic'

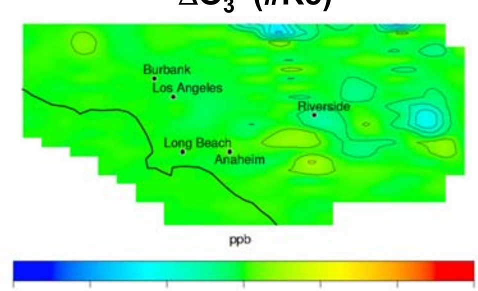
Realistic scenarios:

- #R4 assumes low-early adoption, which implies lower emissions than #R1
- #R5 assumes no CHP emissions displacement, which implies slightly higher emissions than #R1
- #R4 and #R5 produce no significant impacts

ΔO_3 (#R4)



ΔO_3 (#R5)



Spanning Scenarios Summary

Greatest impact of spanning scenarios is on predicted ozone

Some cases show $PM_{2.5}$ impacts

Organization of spanning scenario results

- Spatial Distribution
- Emissions Standards
- DG Adoption Rate
- Large DG and Ammonia Emissions
- Technology mix / DG technology type
- Emissions displacement due to CHP
- In-basin central power plant emissions displacement
- Business-as-usual predictions
- Performance degradation
- Extent of DG penetration
- Temporal emissions rates

Spanning Scenarios Summary

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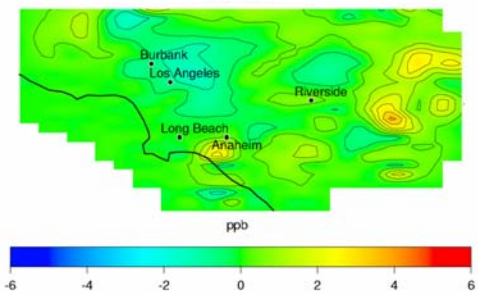
Air Quality Impacts of DG Scenarios – 'Spanning'

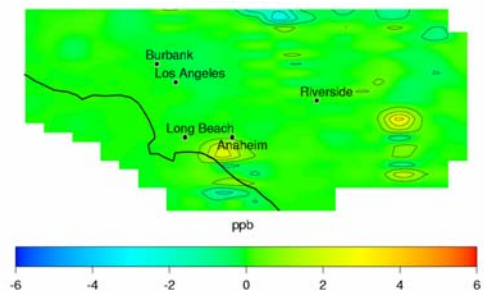
Spanning scenarios – CARB and SCAQMD standards:

- Three scenarios considered: 2003ES, 2007ES and PermICE
- 2003ES and PermICE produce similar impacts:
  - ± 6 ppb changes in ozone concentration
- Impacts produced by 2007ES are lower due to stricter emission standards

ΔO_3 (2003ES)



ΔO_3 (2007ES)

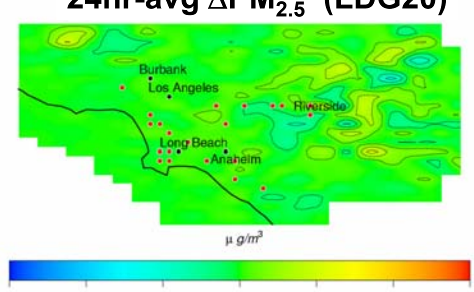


Air Quality Impacts of DG Scenarios – 'Spanning'

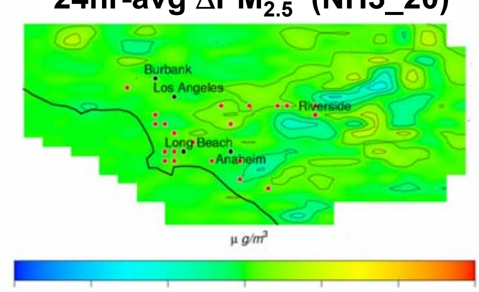
Spanning scenarios – Large DG/Ammonia Slip:

- Two scenarios considered:
  - LDG20: all DG are GT without ammonia emissions
  - NH3_20: same as LDG20 but including ammonia slip emissions
- Ozone concentration is virtually the same in both scenarios
- No significant differences in impacts on $PM_{2.5}$

24hr-avg $\Delta PM_{2.5}$ (LDG20)



24hr-avg $\Delta PM_{2.5}$ (NH3_20)

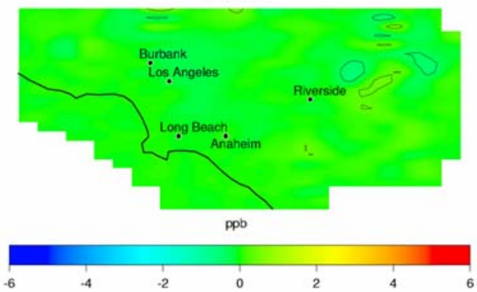


Air Quality Impacts of DG Scenarios – 'Spanning'

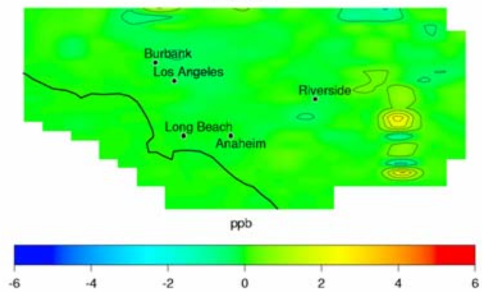
Spanning scenarios – Technology Mix:

- **Scenarios considered:**
  - FCPW20: all DG are fuel cells
  - MTGPW20: all DG are micro-turbine generators
- **Due to low emissions impact on ozone and $PM_{2.5}$ are low**

ΔO_3 (FCPW20)



ΔO_3 (MTGPW20)

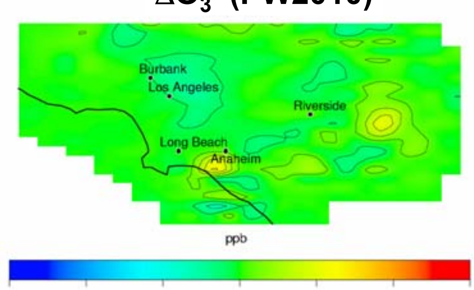


Air Quality Impacts of DG Scenarios – 'Spanning'

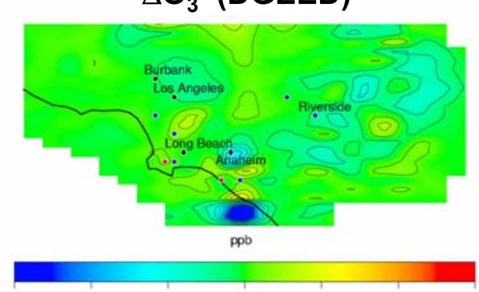
Spanning scenarios – In-basin central plants displacement:

- **DGEED:**
  - same assumptions as in PW2010
  - two power plants (Huntington and Long Beach, red dots) are substituted by large GT (blue dots)
- **DGEED leads to decrease in ozone near Huntington and an increase near Long Beach due to different VOC/NOx regime**

ΔO_3 (PW2010)



ΔO_3 (DGEED)



Summary and Conclusions

- The model shows observable changes/trends in ambient concentrations of ozone and $PM_{2.5}$ due to DG installation
- Air quality impacts of DG for all scenarios throughout basin
  - < 10 ppb for ozone
  - < 6 $\mu g/m^3$ for $PM_{2.5}$
- Simulations predict low air quality impacts for all Realistic DG Scenarios (< 3 ppb O_3; < 2 $\mu g/m^3$ $PM_{2.5}$)
- Maximum increases in pollutant concentrations occur in areas with typically poor air quality (San Bernardino, Riverside)
- DG may increase localized exposure to primary and secondary air pollutants
- Higher levels of DG penetration in out years may lead to significant air quality impacts

Realistic Scenarios Summary

DG Scenario	Parameters that describe each scenario
#R1	• 5% of increased power demand from 2002 to 2010 met by DG • Technology mix according to activity sector distribution • High penetration of low emission technologies • Spatial distribution according to GIS land use distribution • Realistic duty cycle per each sector • CHP emission displaced • Low performance degradation (3% increase of emissions per year) • Linear trend for DG power adoption (Medium early adoption of DG Power)
#R2	• 10% of increased power demand from 2002 to 2010 met by DG • Same assumptions as in #R1 for the rest of parameters
#R3	• 20% of increased power demand from 2002 to 2010 met by DG • Same assumptions as in #R1 for the rest of parameters
#R4	• Low early adoption of DG Power (98% of DG installed in 2007 or after) • Same assumptions as in #R1 for the rest of parameters
#R5	• No CHP emissions displaced • Same assumptions as in #R1 for the rest of parameters

Spanning Scenarios Summary

DG Scenario	Parameters that describe each scenario
PW2010	• 20% of increased power demand from 2002 to 2010 met by DG • Technology Mix – mix of permitted and certified DG: 28.9% large GT (>3 MW), 1.1% small GT (<3 MW), 30% ICE, 25% MTG, 8% PV, 4.9% HTFC, 2.1% LTFC • GT distributed in populated areas with high industrial activity, population weighted spatial distribution for rest of DG • Base-loaded duty cycle • No emission displacement • No performance degradation • Low early adoption of DG Power
2003ES	• Technology Mix - all DG are certified under ARB 2003 Emission Standards • Population weighted spatial distribution • Same assumptions as in PW2010 for the rest of parameters
2007ES	• Technology Mix - all DG are certified under ARB 2007 Emission Standards • Same assumptions as in 2003ES for the rest of parameters

Spanning Scenarios Summary

PermICEPW	• Technology Mix - all DG are ICE operating under BACT criteria • Same assumptions as in 2003ES for the rest of parameters
HEAPW20%	• High Early Adoption of DG Power: 95% of DG is installed before 2007 • Same assumptions as in PW2010 for the rest of parameters
PeakPW	• Peaking duty cycle (6 hours a day) • Peak power demand is equal to base load demand in PW2010 (20% of increased power demand from 2002 to 2010) • Total power delivered by DG during duty cycle • Technology Mix - mix of permitted and certified DG: 33.9 % large GT (>3 MW), 1.4% small GT (<3 MW), 35.3% ICE, 29.4% MTG • Same assumptions as in PW2010 for the rest of parameters
LDG20%	• Technology Mix – all DG are 49MW GT • No ammonia emissions from DG considered • GT distributed in populated areas with high industrial activity • Same assumptions as in PW2010 for the rest of parameters
NH3_20%	• Ammonia emissions from GT considered • Same assumptions as in LDG20% for the rest of parameters

Spanning Scenarios Summary

PGW20%	• GT distributed in populated areas with high industrial activity, population growth weighted spatial distribution for rest of DG • Same assumptions as in PW2010 for the rest of parameters
LUW20%	• GT distributed in populated areas with high industrial activity, land use weighted spatial distribution for rest of DG • Same assumptions as in PW2010 for the rest of parameters
Free20%	• GT distributed in populated areas with high industrial activity, freeway weighted spatial distribution for rest of DG • Same assumptions as in PW2010 for the rest of parameters
FCPW20%	• Technology Mix – All DG are Fuel Cells • Population weighted spatial distribution • Same assumptions as in PW2010 for the rest of parameters
MTGPW20%	• Technology Mix – All DG are certified MTG • Population weighted spatial distribution • Same assumptions as in PW2010 for the rest of parameters

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Spanning Scenarios Summary

DGCHP	• CHP emissions displaced • Same assumptions as in PW2010 for the rest of parameters
DGEED	• All Electricity Emissions Displaced from in-basin Electricity Generators • Same assumptions as in PW2010 for the rest of parameters
TDPW10%	• 10% of increased power demand from 2002 to 2010 met by DG • Technology Mix – 34% NG ICE, 46% MTG, 10% FC, 10% PV • Population weighted spatial distribution • Fuel Cells are base loaded, rest of DG operates in a 6-hour duty cycle (from 12 pm to 6 pm) • Same assumptions as in PW2010 for the rest of parameters
BAU	• Linear extrapolation from current data on 2001 and 2002 DG installations in the SoCAB to determine total DG power installed in 2010 • Technology Mix – Mix of permitted and Certified DG from current DG mix data • Medium early adoption of DG Power • Same assumptions as in PW2010 for the rest of parameters
EHP	• Extra high DG penetration: 20% of total power met by DG • Same assumptions as in PW2010 for the rest of parameters

Spanning Scenarios Summary

BAU_par	• Parabolic extrapolation from current data to determine total DG power installed in 2010 • Same assumptions as in BAU for the rest of parameters
HPD	• High performance degradation: 10% increase of emissions per year • Same assumptions as in PW2010 for the rest of parameters
PeakPW_2	• Peaking duty cycle (6 hours a day) • Peak power demand is 4 times the base load demand in PW2010 so that Total cumulative electricity delivered by DG during duty cycle equals the DG electricity in the PW2010 • Technology Mix - mix of permitted and certified DG: 33.9 % large GT (>3 MW), 1.4% small GT (<3 MW), 35.3% ICE, 29.4% MTG • Same assumptions as in PW2010 for the rest of parameters