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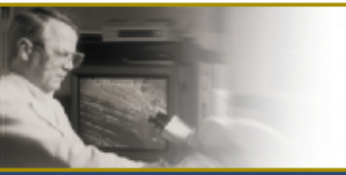
CLEAN ENERGY TECHNOLOGIES

Fernando Preto

EMISSIONS FROM RESIDENTIAL WOOD COMBUSTION

IEA Task 32 Workshop
Recent Developments in Small Scale Combustion Devices
Paris, October 21, 2005

Canada

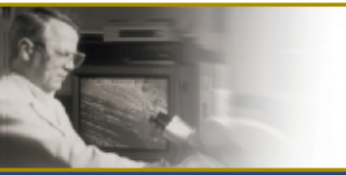


Objectives

To study hazardous emissions from residential wood combustion devices in order to to provide information for reducing the amount of particulates, VOCs and dioxins and furans and update database of the current contribution of residential appliances to Canadian air sheds

Hazardous Substances Evaluated:

- Particulate Matter
- Volatile Organic Compounds
- Dioxins and Furans



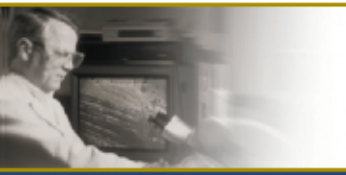
Background

Residential wood combustion currently accounts for 15% of biomass energy use in Canada (0.9 % of Canada's primary energy use)

Environment Canada has estimated that 14% of total national $PM_{2.5}$ emissions from anthropogenic sources (excluding forest fires) are from residential combustion systems

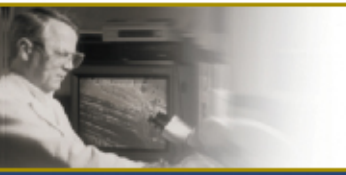
Environment Canada has estimated that 15% of total national VOC emissions are from residential combustion systems

Canada



Emissions Requirements

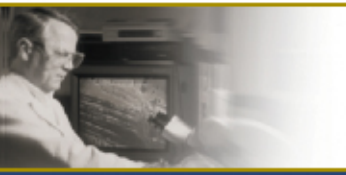
- The United States has national emissions requirements, and these apply only to a limited range of appliances, generally those which would be considered to be wood stoves. U.S. emission limits are 7.5 g/h for non-catalytic appliances and 4.1 g/h for catalyst equipped appliances. These figures compare to typical emissions of approximately 20 - 30 g/h for pre-regulation appliances.
- In Canada, the province of British Columbia has adopted the U.S. requirements. In the rest of Canada there are currently no requirements for wood burning appliances to meet any emissions criteria
- Environment Canada, the federal department responsible for such regulation, has initiated the process necessary for adoption of a national regulation
- Canada does have an emissions and efficiency test protocol but it has yet to be mandated by the regulatory authorities.



Canadian Standards

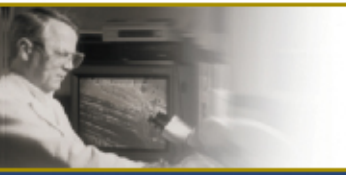
The principal Canadian standards dealing with wood heat systems are summarized below.

- ULC S627 (Cdn), UL1482 (U.S.): Wood and pellet stove safety testing. This standard sets minimum requirements for the construction and clearances to combustibles of wood stoves, including pellet-fired appliances.
- ULC S628 (Cdn), UL737 (U.S.) Similar to S627 but covering inserts.
- CSA B365(Cdn): Sets out installation requirements of wood burning appliances, including uncertified equipment.
- CSA B366.1 (Cdn), UL 391 (U.S.): Requirements similar to S627 for central wood burning systems.
- CSA B415.1 (Cdn), EPA Part 40 (U.S.): Test methods for determination of efficiency and particulate emissions from wood-fired appliances, including conventional and pellet stoves, inserts, central furnaces and boilers, small commercial systems, and “high performance” fireplaces. Maximum particulate emission levels are specified. An ASTM document is also being developed to provide testing requirements for outdoor boilers (WK 5982).



Experimental Program

- Appliance type:
  - Level 1: conventional “old” cordwood (FMB)
  - Level 2: conventional “new” cordwood (CTS)
  - Level 3: certified cordwood (RCY)
  - pellet stove (DPP)
- Burn rate:
  - Low: 1.5 kg/hr cordwood
  - High: 3.0 kg/hr cordwood
- Fuel:
  - hardwood - red oak; moisture 15% and 35%
  - Softwood – pine; moisture 15% and 35%

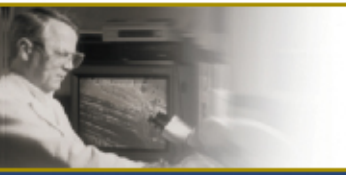


Level 1 Appliance (FMB)

- “box with a hole in the back”
- partial sidewall refractory lining only

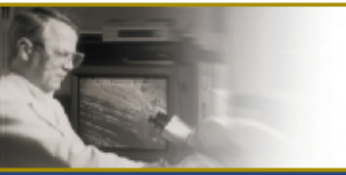
Level 2 Appliance (CTS)

- current “conventional” design
- baffle at back near exit
- partial refractory lining

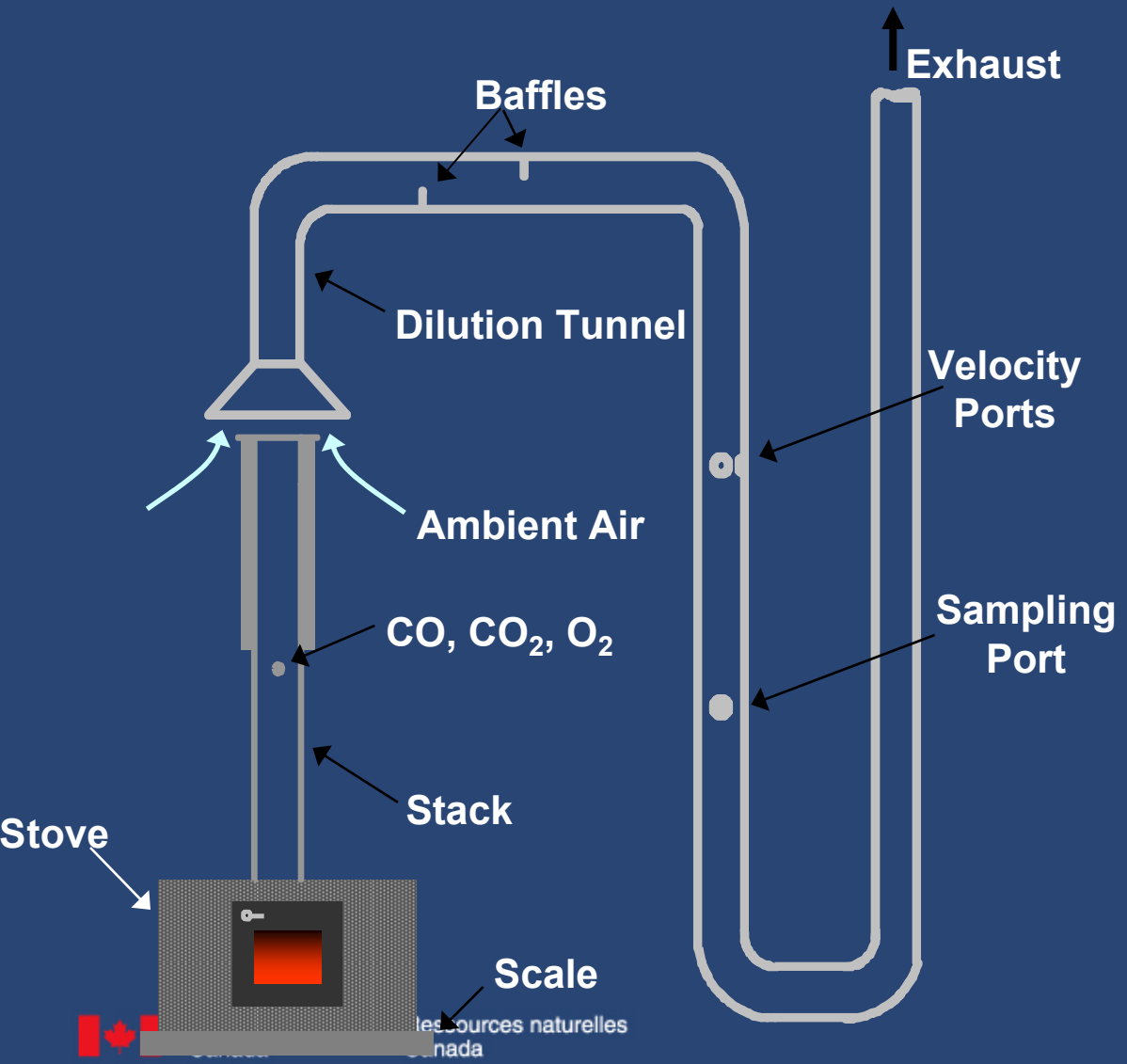


Level 3 Appliance (RCY)

- USEPA Certified Stove
- Full refractory
- Refractory baffle
- Air staging



Sampling Set-up

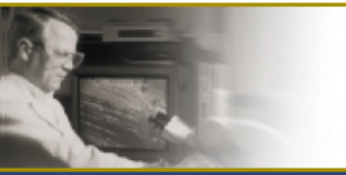


"Real Life" Experimental Procedure

1. Small fire started with newspaper & kindling
2. Pre-test charge loaded & desired air rate set
3. Pre-test charge burnt until 20-25% remained
4. Start: test charge loaded & PM sampling started
5. End: test charge consumed & sampling stopped

All of the cordwood was split and the bark was intact. As fuel size can affect emission rates, it was kept as constant as possible. The cross-section of the fuel pieces ranged between 65 and 130 cm2 and the length was 40 cm.

Canadian Standards Association
Technical Standard B415.1 Performance Testing
of Solid-Fuel-Burning Appliances



Particulate Sampling

Particulate Sampling:

- sampling head disassembled
- filter placed in dessicator
- cyclones brushed & rinsed with acetone, rinses transferred to 3 beakers (>10µm, <10 µm & >2.5 µm, <2.5 µm)
- acetone evaporated, beakers placed in dessicator
- mass of each size fraction determined gravimetrically

Combined Cyclone Sampling Head

VOC Sampling

VOC Sampling:

- **Collected using Method 30 – VOST which measures 35 VOCs**
- **Replace Tenax cartridge pairs after 40 minutes to ensure VOC capture**

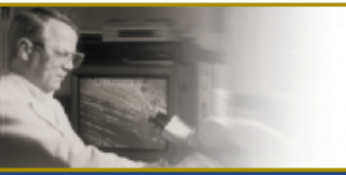
Volatile Organic Compound (VOC)

- Any carbon containing compound which participates in atmospheric photochemical reactions
- Most commonly Includes:

  Acetone; Acrylonitrile; Benzene; Carbon disulfide; Carbon tetrachloride; Chlorobenzene; Chloroethane; Chloroform; Chloromethane; Ethylbenzene; Iodomethane; Methylene chloride; Styrene; Toluene; Vinyl chloride; Xylenes.

  Bromodichloromethane; Bromoform; Bromomethane; Chlorodibromomethane; Dibromomethane;

  1,1-Dichloroethane; 1,2-Dichloroethane; 1,1-Dichloroethene X; trans-1,2-Dichloroethene; 1,2-Dichloropropane; cis-1,3-Dichloropropene; trans-1,3-Dichloropropene;; 1,1,2,2-Tetrachloroethane; Tetrachloroethene; 1,1,1-Trichloroethane; 1,1,2-Trichloroethane; Trichloroethene; Trichlorofluoromethane; 1,2,3-Trichloropropane.
- Excludes carbon monoxide, carbon dioxide, methane, ethane, metallic carbides or carbonates, ammonium carbonate and carbonic acid



VOC Results

- Cordwood Stove VOC emissions range:
  - **38 mg/kg fuel**
    (certified, hardwood, low moisture, high burn rate)
  - **13,097 mg/kg fuel**
    ("old" stove, softwood, high moisture, low burn rate)

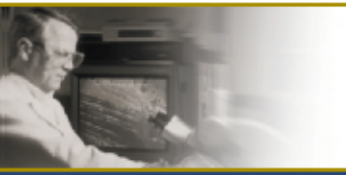
- VOC Species
  - **most species were "Non-Detect"**
  - **samples contained primarily BTEX**
    (benzene, toluene, ethylbenzene, xylene)
    & styrene

Particulate Matter Results

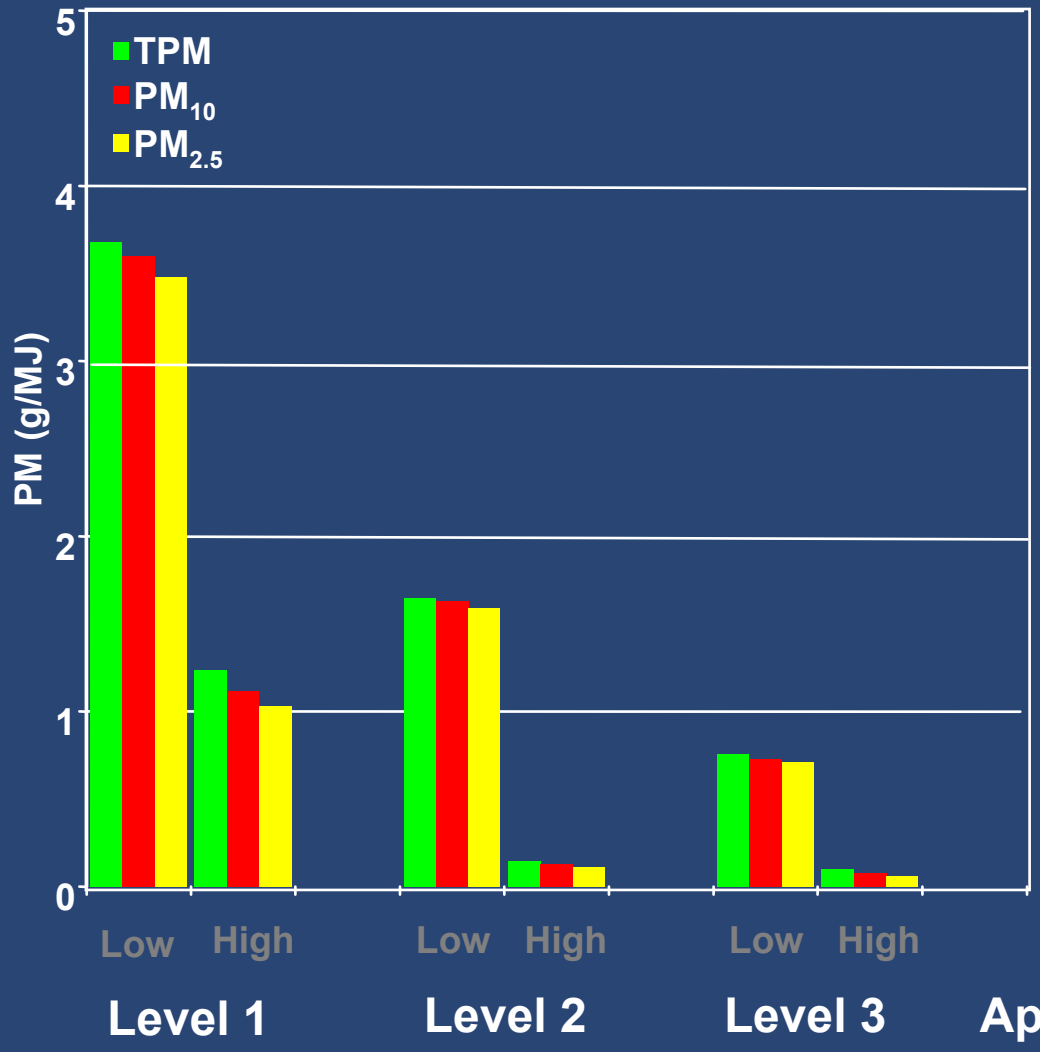
Total PM emissions ranged from 0.019 g/MJ for the pellet stove operated at a high burn rate to 3.68 g/MJ for the “old” conventional stove operated at a low burn rate. Average emissions are 1.68 g/MJ for the conventional cordwood stove and 0.44 g/MJ for certified non-catalytic stoves.

Database of Run Conditions

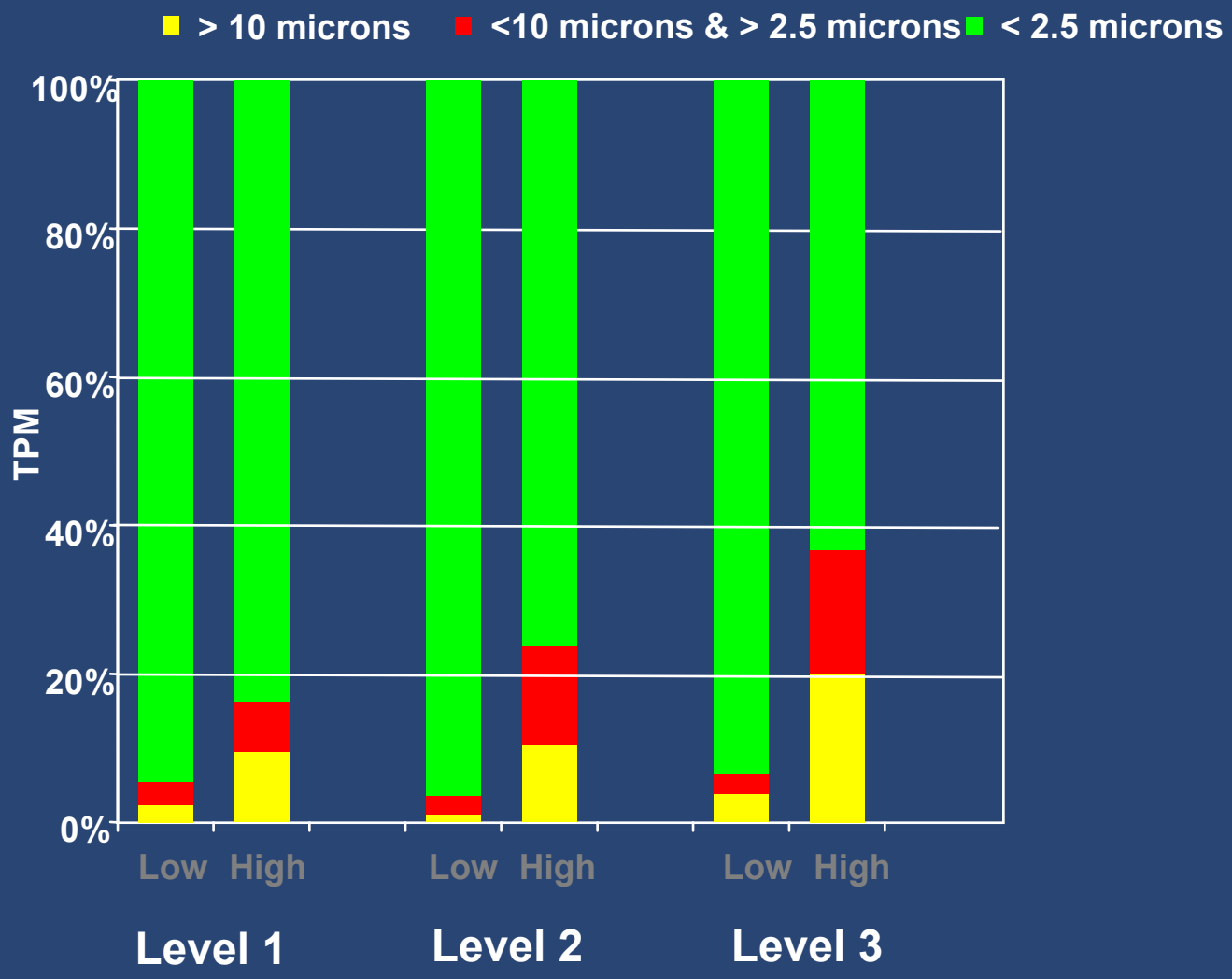
Appliance Type	Dry Fuel Load (kg)	Dry Burn Rate (kg/hr)	Flue Conditions			Appliance Efficiency (%)
			Temp. (°C)	CO_2 (%)	CO (ppm)	
Level 1	5.36	1.78	150	7.9	14165	61.8
Level 1	5.48	3.16	251	9.2	8922	64.6
Level 2	3.61	1.78	150	8.5	11729	57.1
Level 2	3.62	3.04	291	14.6	12472	66.3
Level 3	5.05	1.54	160	7.3	4244	82.8
Level 3	4.73	3.44	295	11.3	3103	71.8
Pellet	4.19	0.84	93	6.5	88	85.6
Pellet	6.98	1.40	139	13.3	65	85
Pellet	6.79	1.36	135	13	50	90.6

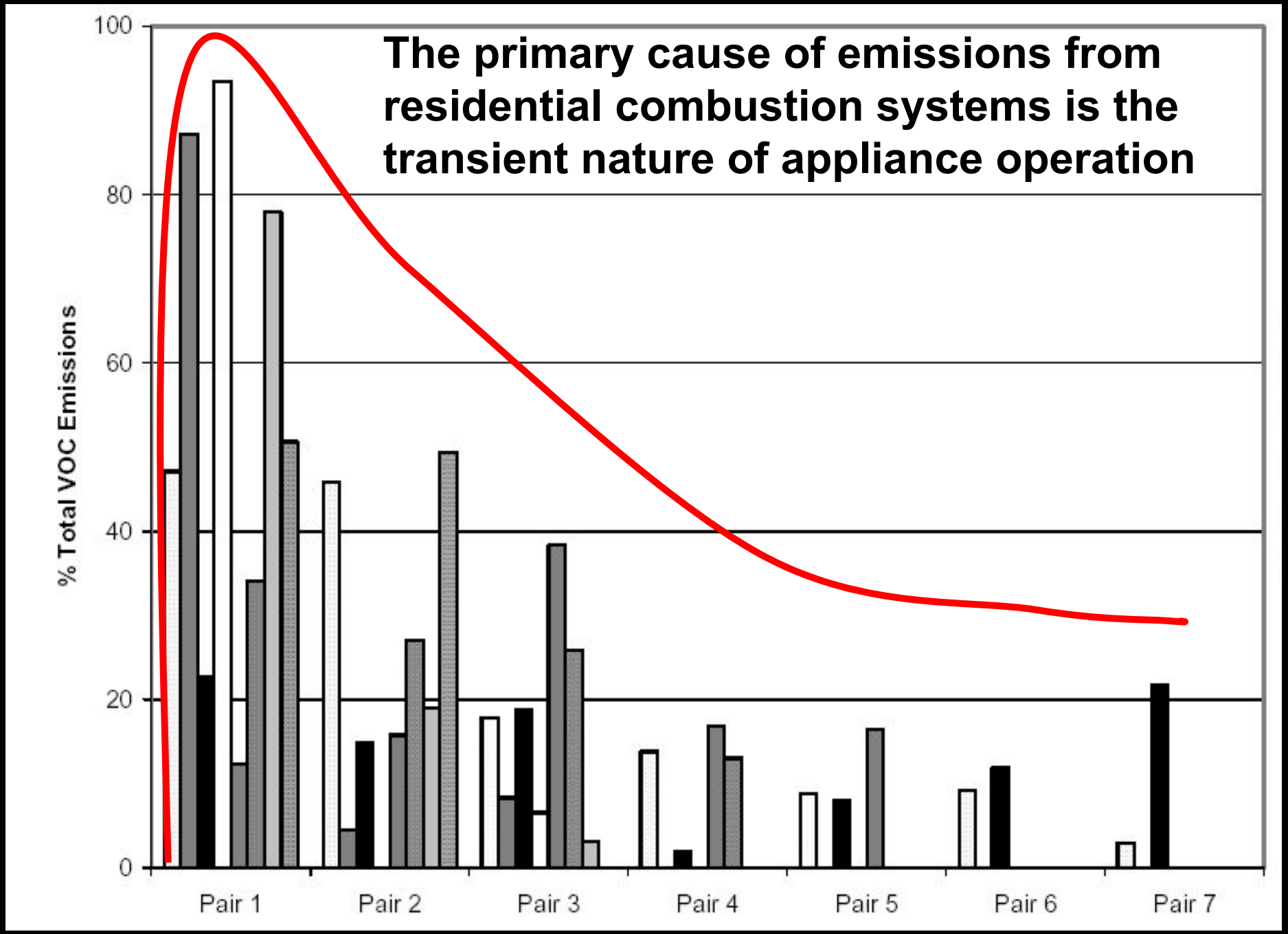


Effect of Appliance Design on PM

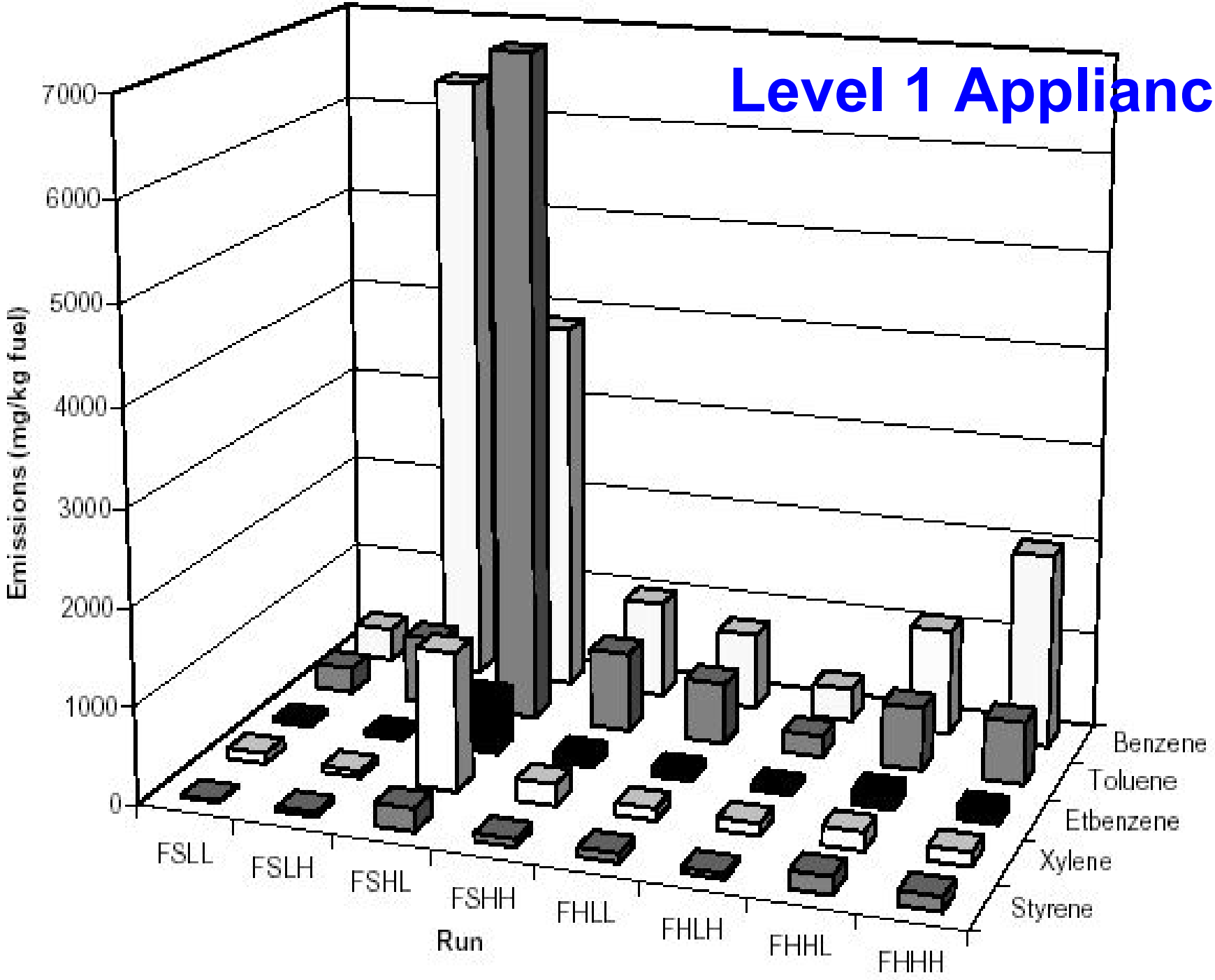


PM Size Distribution

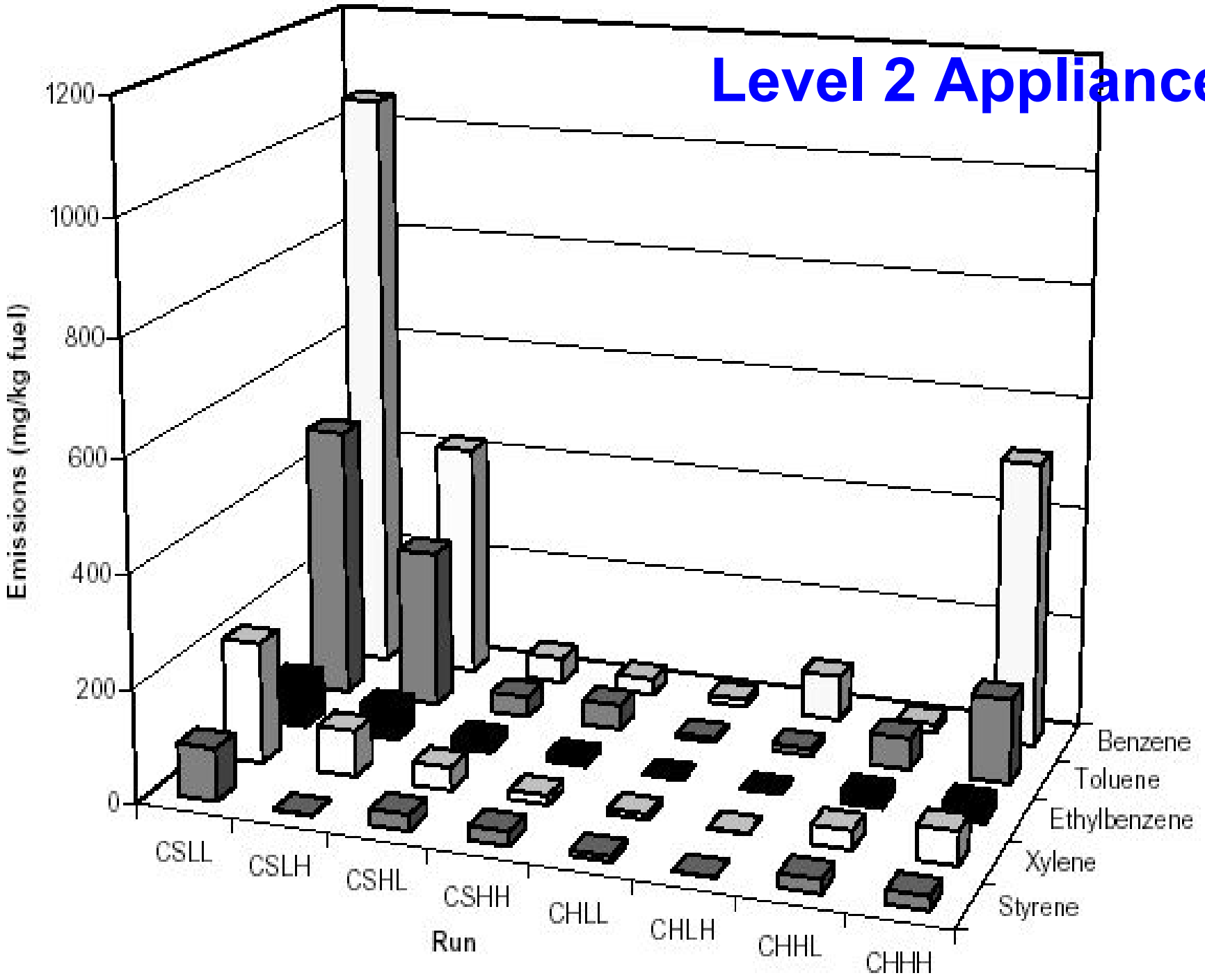



The primary cause of emissions from residential combustion systems is the transient nature of appliance operation
% Total VOC Emissions
100
80
60
40
20
0
Pair 1
Pair 2
Pair 3
Pair 4
Pair 5
Pair 6
Pair 7

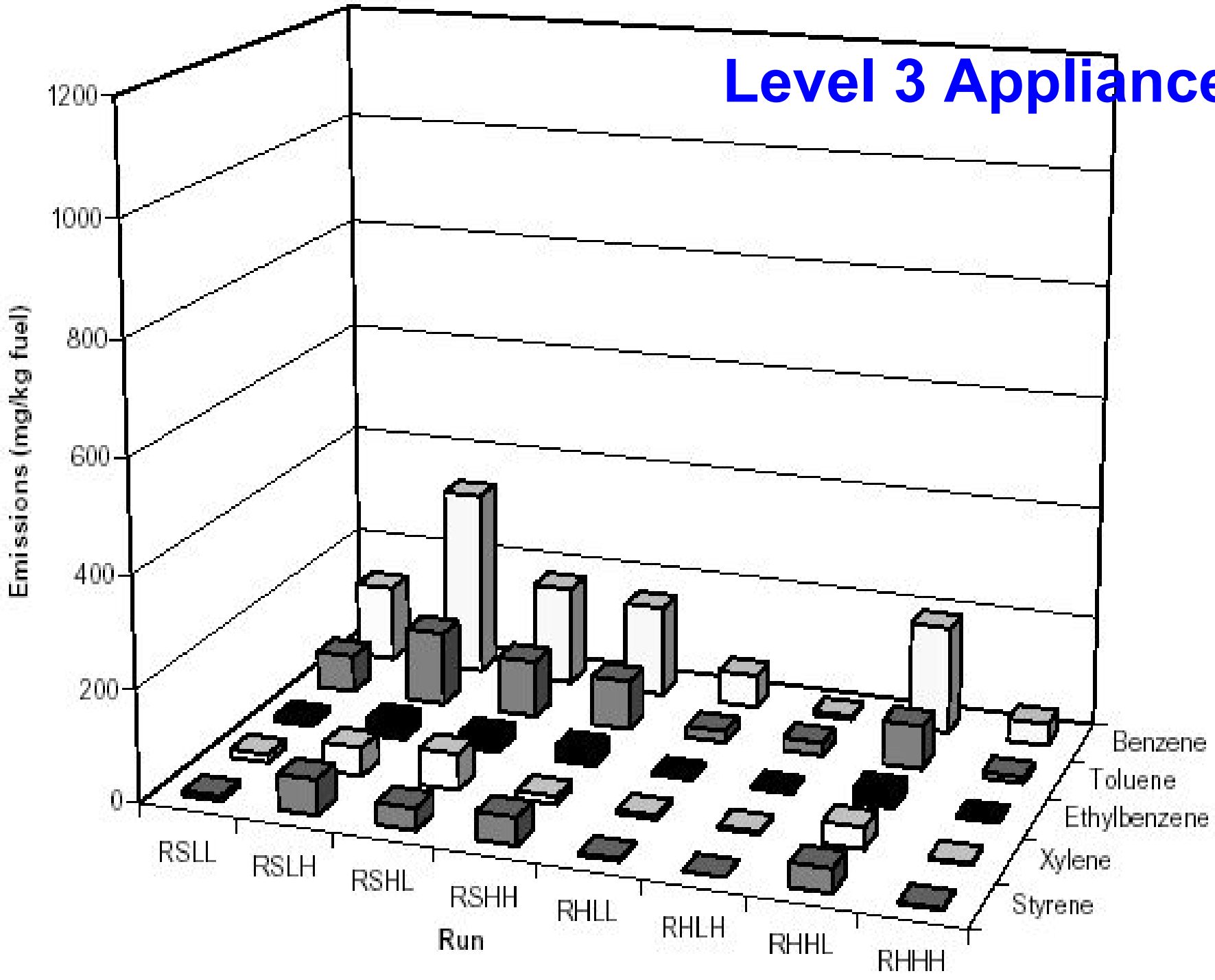
Level 1 Appliance

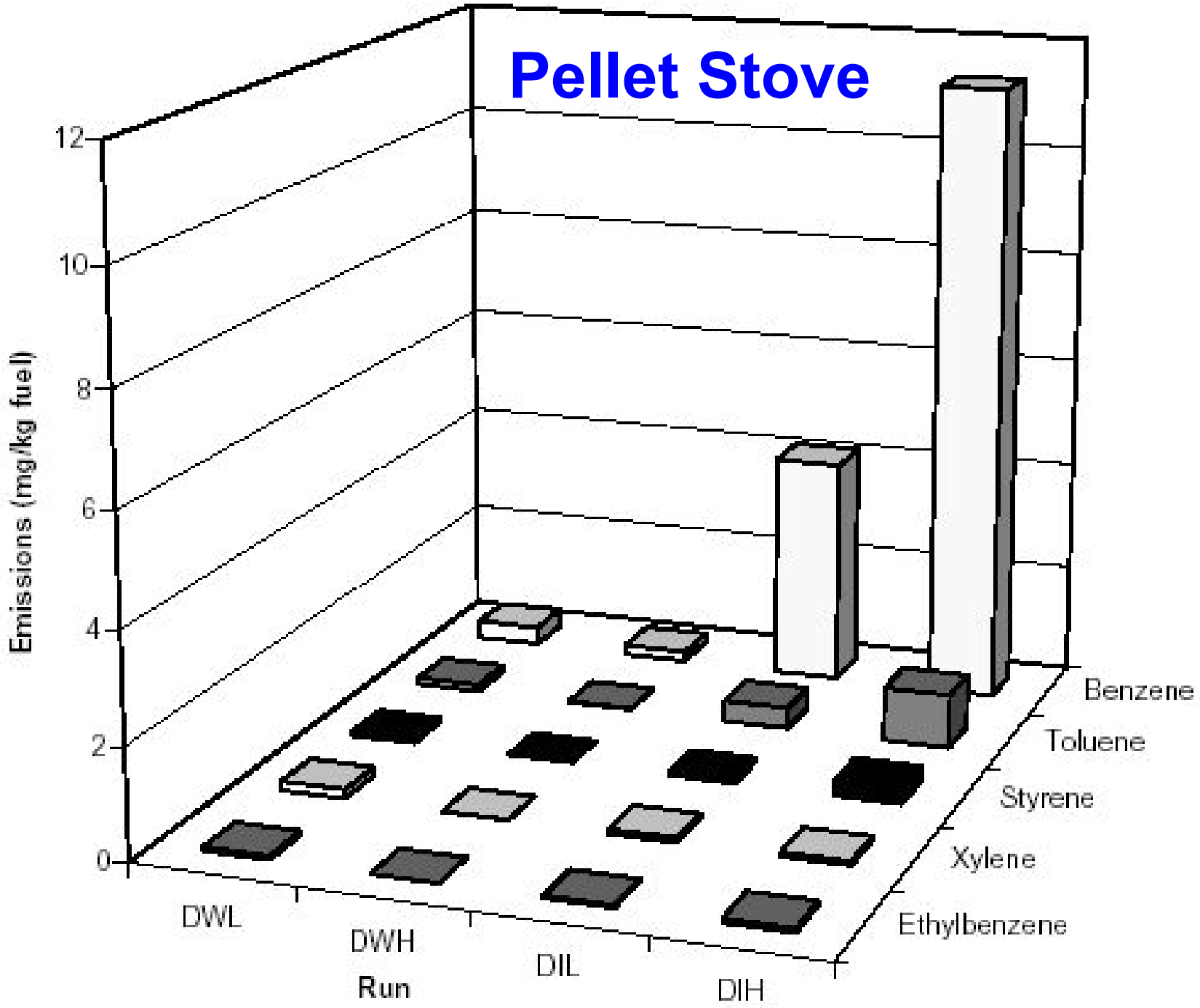


Level 2 Appliance



Level 3 Appliance

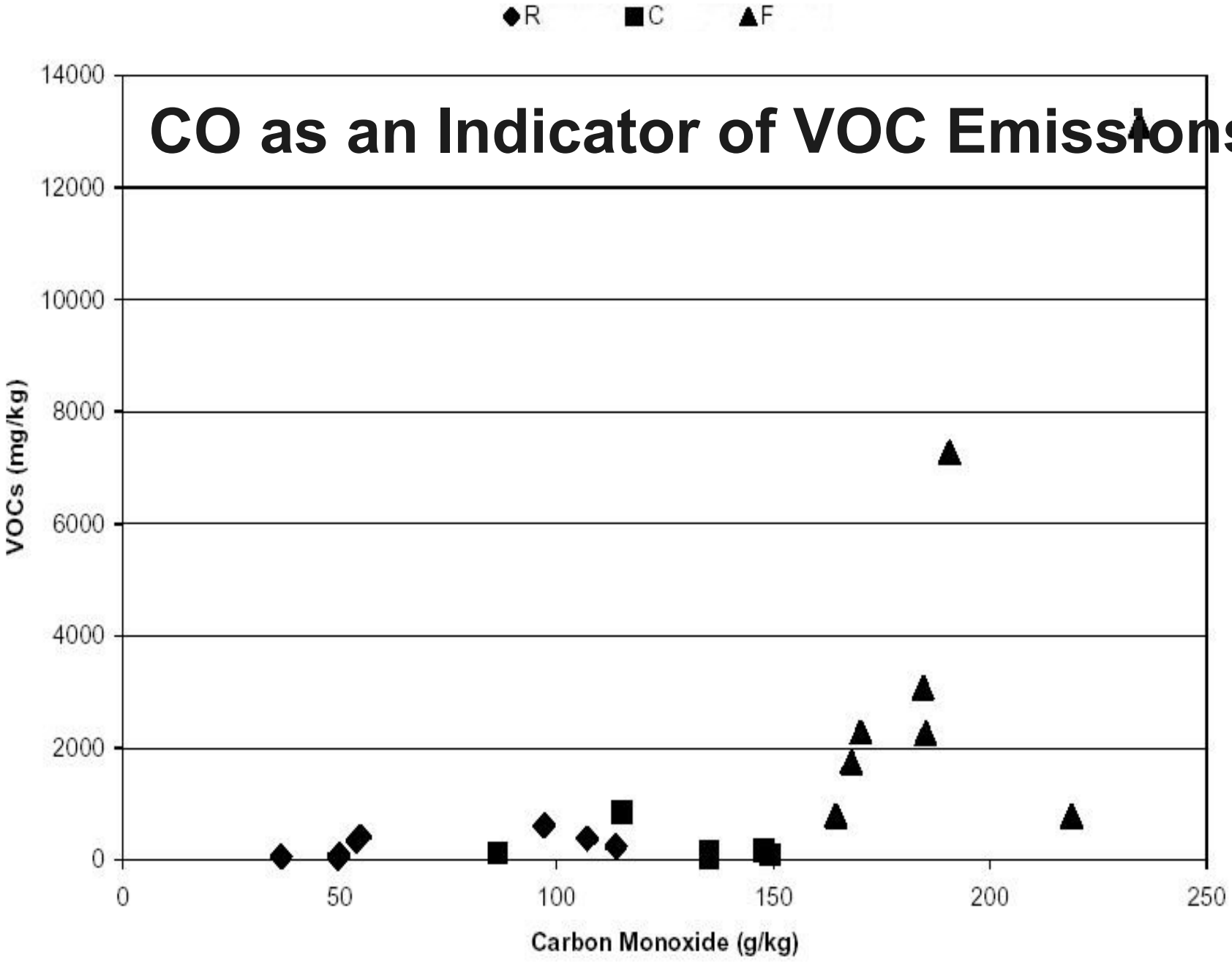


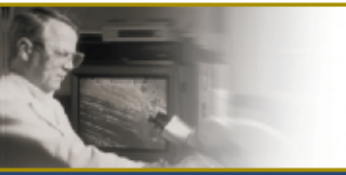

Pellet Stove
Emissions (mg/kg fuel)
12
10
8
6
4
2
0
DWL
DWH
DIL
DIH
Run
Benzene
Toluene
Styrene
Xylene
Ethylbenzene

Transient vs Steady State Operation

	Cord Wood Stoves	Pellet stove	
Efficiency	55 – 83	85 – 90	%
CO	300 – 14,000	50 – 90	ppm
PM	1.5 – 72.1	0.33 – 0.74	g/kg
VOC	38 – 13,100	0.02 – 13	mg/kg

CO as an Indicator of VOC Emissions





Hazardous Emissions

Appliance design is by far the most important factor in reducing hazardous emissions.

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Level 3 Appliance (RCY)

- USEPA Certified Stove
- Full refractory
- Refractory baffle
- Air staging

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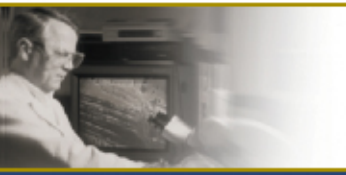
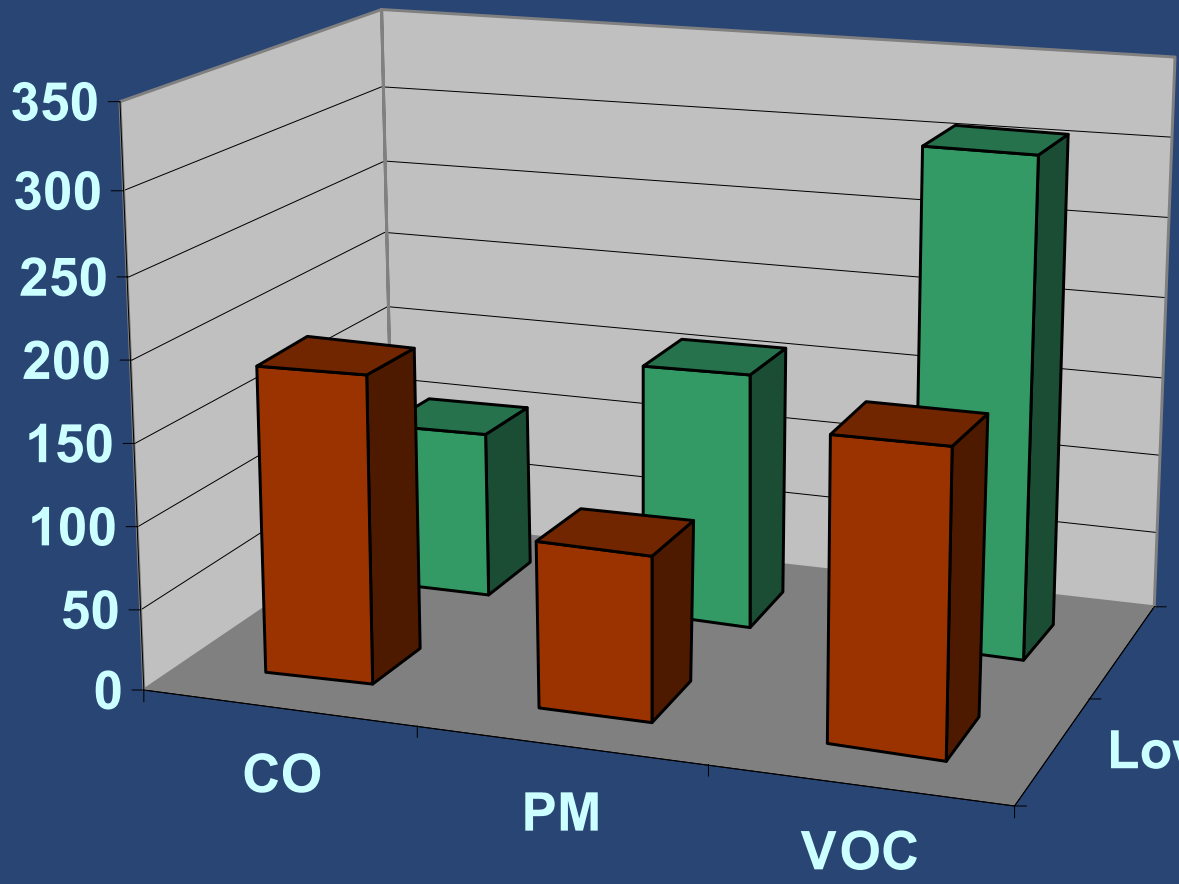
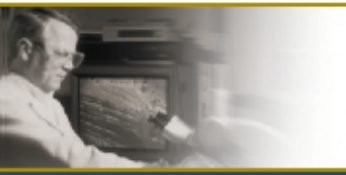
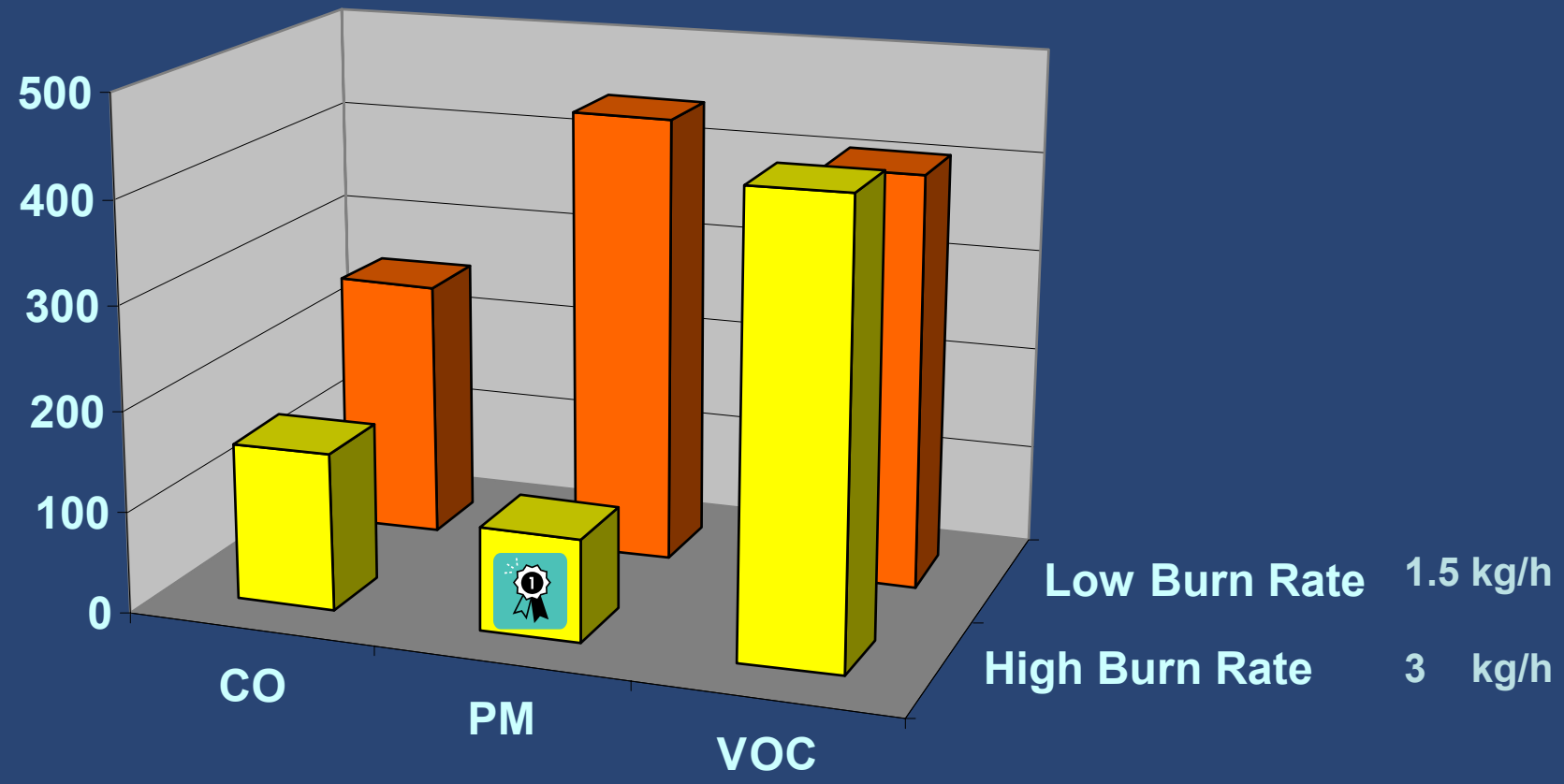


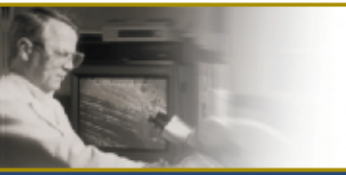
Effect of Moisture on Emissions



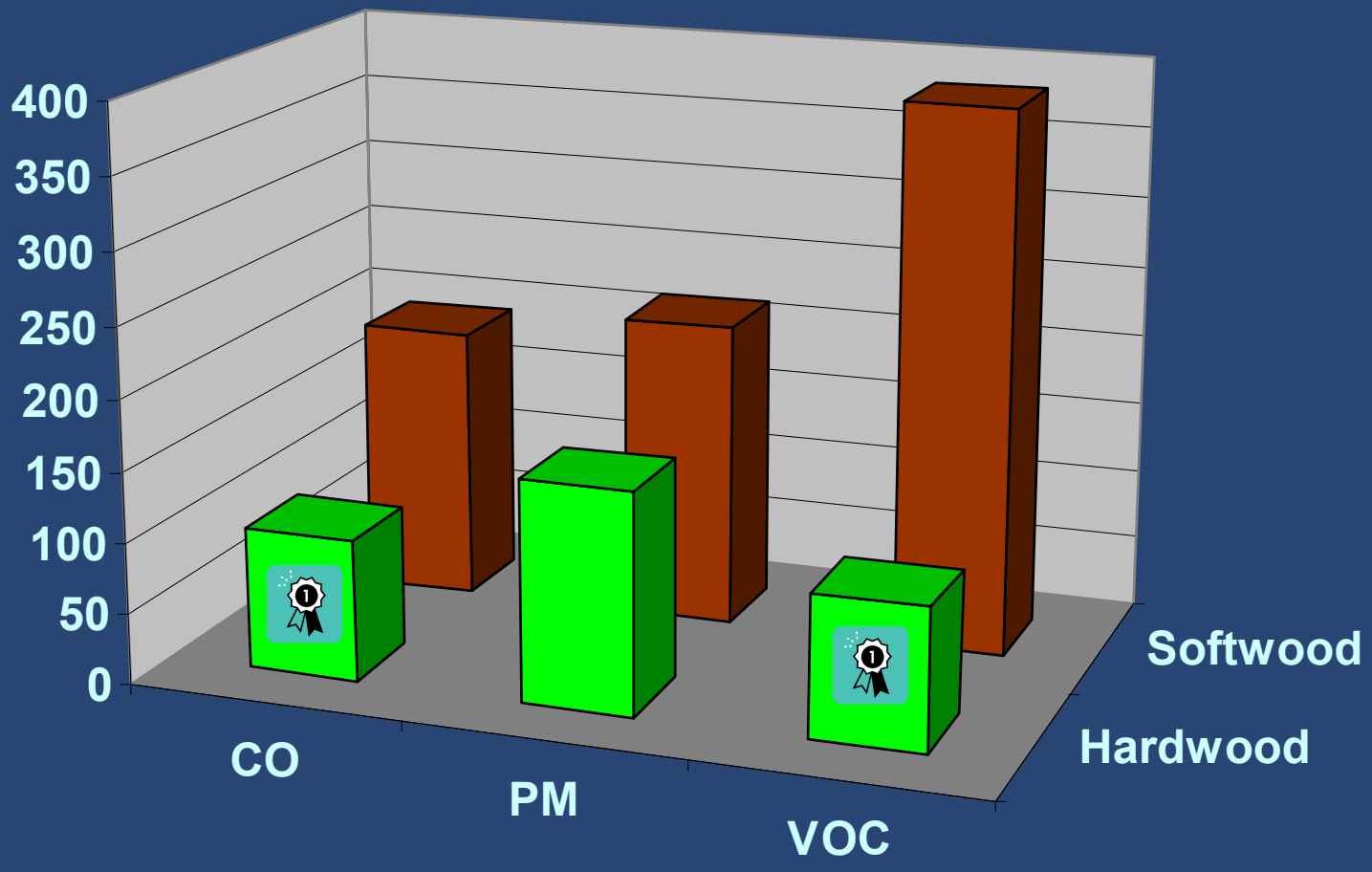


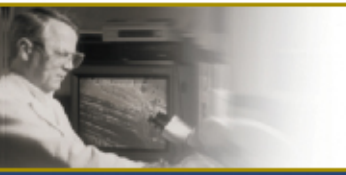
Effect of Firing Rate on Emissions





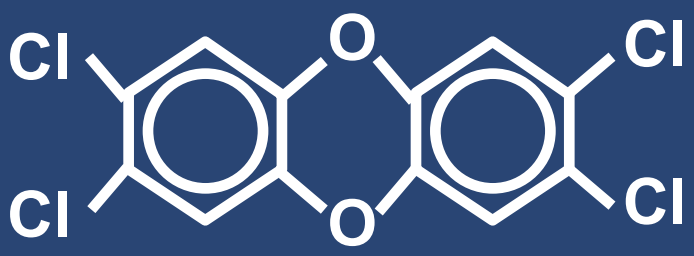
Effect of Wood Type on Emissions





Dioxins and Furans

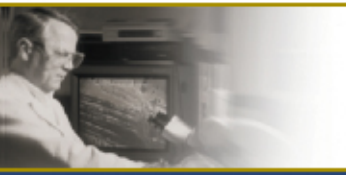
Dioxin (PCDD)



In 1999 Environment Canada identified residential wood use as a major source of dioxins and furans (PCDDs and PCDFs).

Furan (PCDF)

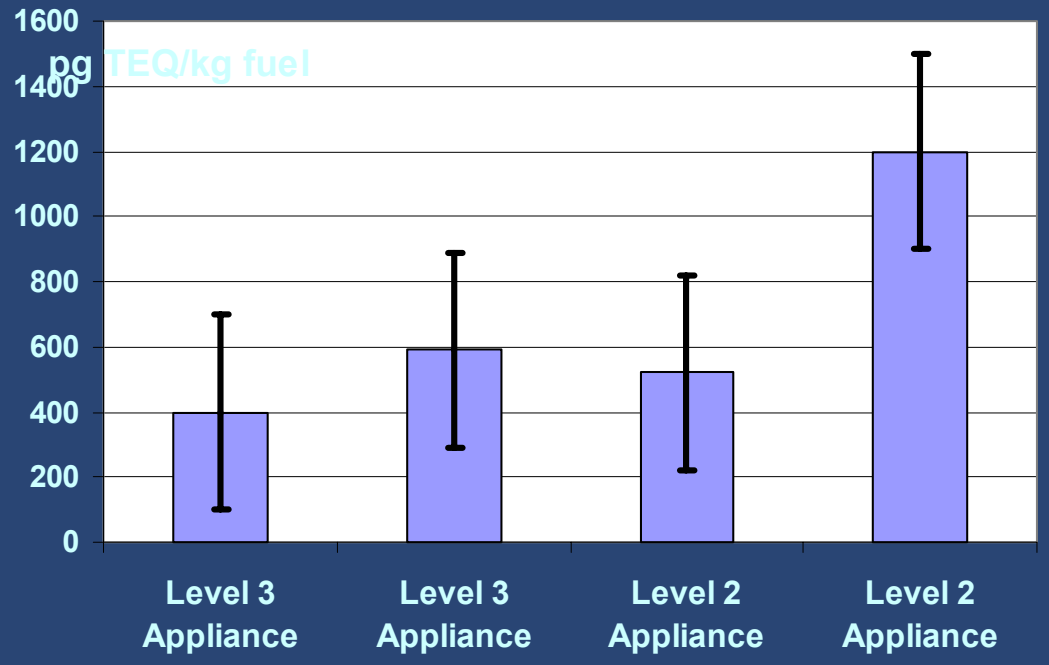
Environment Canada research however indicated that additional testing was required to verify exisiting data and better understand PCDDs and PCDFs formation in residential systems.



Dioxins and Furans

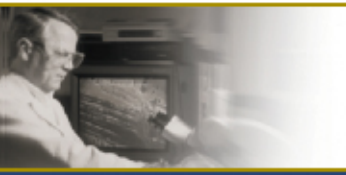
Due to test conditions with large run-to-run differences and large uncertainty ranges, no conclusions regarding the effect of woodstove type or operating conditions can be made from a series of 8 PCDD/F tests.

The average total PCDD and PCDF emission factor was 669 pg TEQ/kg dry fuel. This value is consistent with results from other studies.



Comparison with other studies

Study	Average Emission Factor (pg TEQ/ kg dry fuel)
NRCan	669
Gullett *et al.*[5] & Crouch and Houck [6]	250
EC[2]	677
Vikelsoe *et al.*[7]	1900



Conclusions

- Residential wood-burning PM is composed primarily of $PM_{2.5}$
- The most prevalent VOC compounds are BTEX (benzene, toluene, ethylbenzene, xylene) and styrene. Most of the other compounds analyzed for were not present above the method detection level.
- Of the VOCs detected, cordwood stoves emissions were composed primarily of benzene (48%) and toluene (28%).
- Additional protocol development is needed to allow detailed study of dioxin/furan formation
- Advanced technology appliances, such as pellet and certified cordwood stoves, produce substantially less hazardous emissions than conventional cordwood stoves.
- The use of hardwood as the fuel substantially reduces emissions as compared to softwood fuel.
- In general, lower fuel moisture and high burn rates result in lower emissions but there is no consistent effect on all hazardous emissions.

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Thank you

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