

MOVES2004

Energy & Emission Inputs

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EPA Office of Transportation & Air Quality

MOVES2004 Workshop

March 16, 2005

The word "MOVES" is displayed in a stylized, metallic, three-dimensional font with a brushed metal texture and a slight shadow effect, set against a dark rectangular background.

Acknowledgements

- **Co-Authors: Larry Landman, Ed Nam, Ed Glover, Jim Warila, Carl Scarbro, Bob Giannelli**

Outline

- **Emission Rate Characterization**
- **Total Energy Rates**
 - Running
 - Start
 - Extended Idle
- **Petroleum & Fossil-Based Energy**
- **CH₄ & N₂O Rates**
- **Advanced Technology & Future Rates**
- **Adjustments**
- **Well-To-Pump Rates**

Emission Rate Characterization Depends on Pollutant/Process

- **Each pollutant/process is unique in terms of:**
 - Activity characteristics that need to be accounted for
 - Operating Mode definitions
 - Vehicle characteristics that need to be accounted for
 - Source Bins definitions
 - Available data → appropriate level of aggregation
- **MOVES is designed with flexibility to define each pollutant/process uniquely**
 - Although for simplicity it is desirable to have common definitions where possible, esp. across pollutant

Emission Rate Characterization

- **Running**
 - Energy: modal emission rates (KJ/SO by bin)
 - CH₄ & N₂O: aggregate emission rates (KJ/SO)
- **Start**
 - Incremental energy/emissions per start
- **Extended Idle**
 - Per hour of extended idle (energy only)
- **Well-To-Pump**
 - Well-to-pump energy/emissions per KJ consumed on-road

Running Energy Rates

- **Source Bins**
- **Operating Mode Bins**
- **Data Sources**
- **Binning Methodology**
- **Hole Filling**

Source Bin Fields for Energy Rates

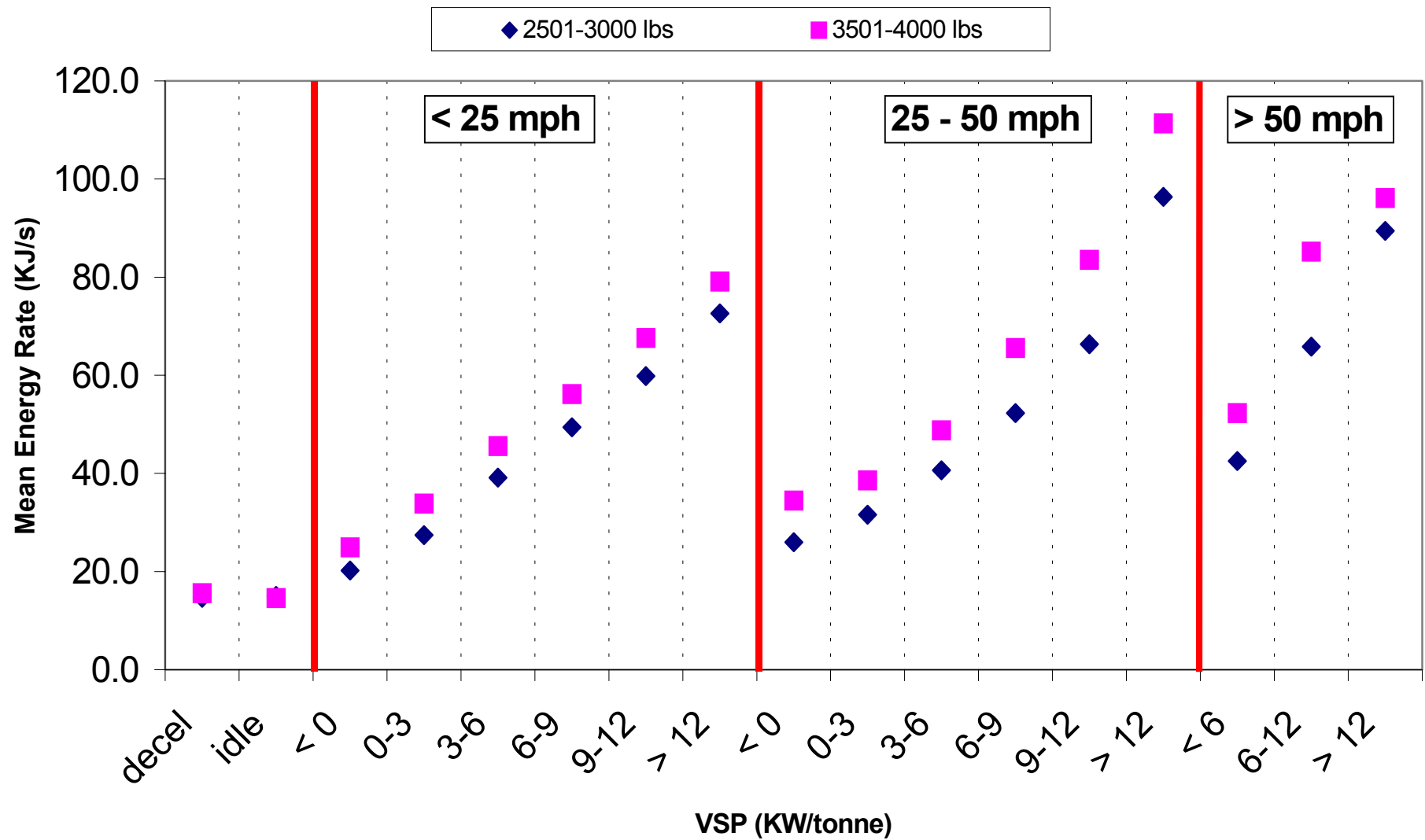
Fuel Type	Engine Technology	Model Year Group	Loaded Weight	Engine Size
Gas	Conventional IC (CIC)	1980 and earlier	Null	Null
Diesel	Advanced IC (AIC)	1981-85	<= 2000 lbs	< 2.0 liters
CNG	Moderate Hybrid - CIC	1986-90	2001-2500	2.1-2.5 liters
LPG	Full Hybrid - CIC	1991-2000	2501-3000	2.6-3.0 liters
Ethanol (E85)	Moderate Hybrid - AIC	2001-2010	3001-3500	3.1-3.5 liters
Methanol (E85)	Full Hybrid - AIC	2011-2020	3501-4000	3.6-4.0 liters
Gas H ₂	Fuel Cell	2021 and later	4001-4500	4.1-5.0 liters
Liquid H ₂	Hybrid - Fuel Cell		4501-5000	> 5.0 liters
Electric			5001-6000	
			6001-7000	
			7001-8000	
			8001-9000	
			9001-10,000	
			10,001-14,000	
			14,001-16,000	
			16,001-19,500	
			19,501-26,000	
			26,001-33,000	
			33,001-40,000	
			40,001-50,000	
			50,001-60,000	
			60,001-80,000	
			80,001-100,000	
			100,001-130,000	
			>=130,001	

Operating Mode Bins for Running Energy

Braking (Bin 0)			
Idle (Bin 1)			
VSP \ Speed	0-25mph	25-50	>50
< 0 kw/tonne	Bin 11	Bin 21	
0 to 3	Bin 12	Bin 22	
3 to 6	Bin 13	Bin 23	
6 to 9	Bin 14	Bin 24	
9 to 12	Bin 15	Bin 25	
12 and greater	Bin 16	Bin 26	Bin 36
6 to 12			Bin 35
< 6			Bin 33

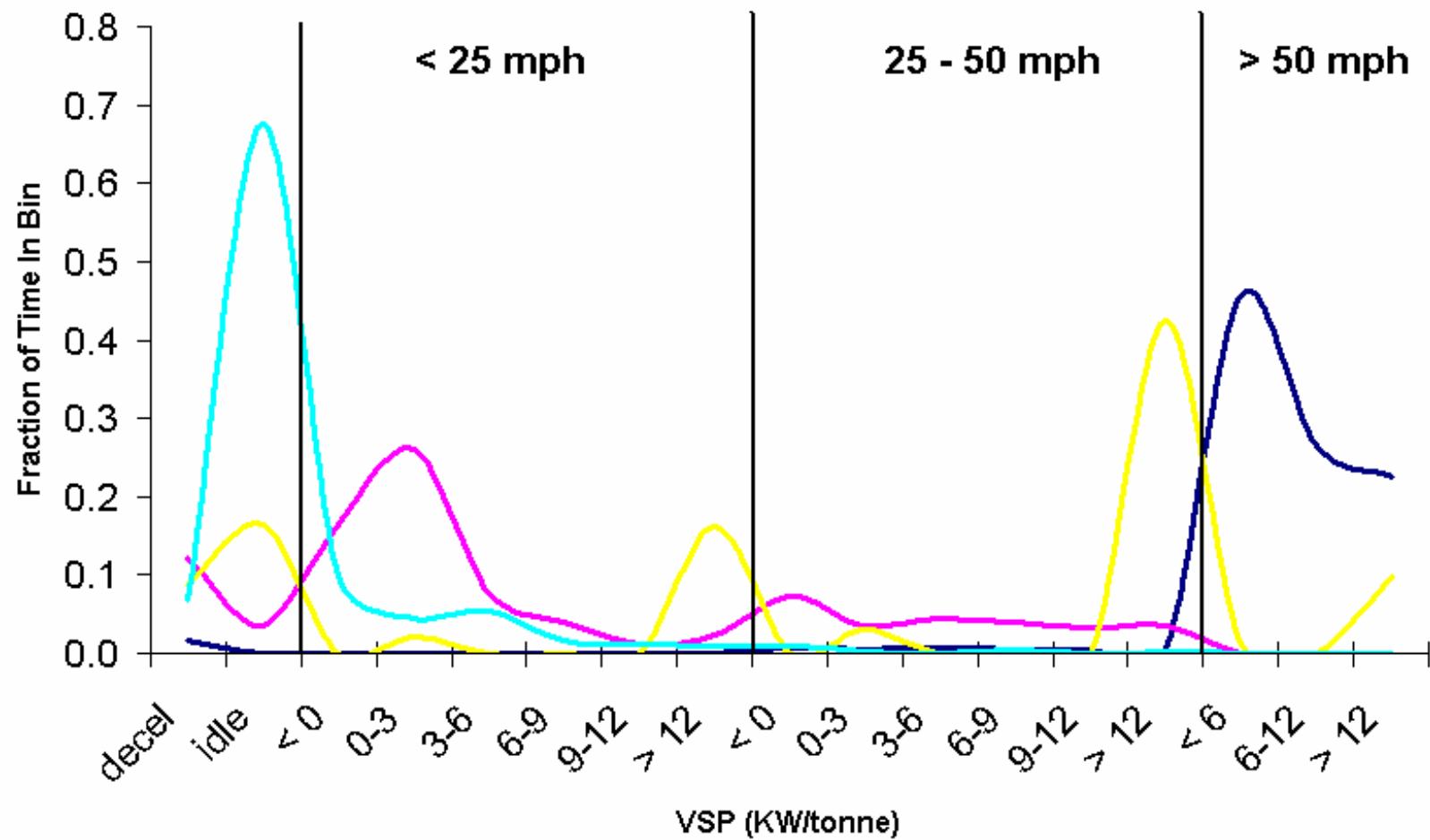
Energy Consumption Rates By Bin

Source Bin: Gasoline / 86-90 MY / 2.0-2.5 liter



Distribution of Time By Bin

- Uncongested Freeway
- Congested Freeway
- Moderate Speed Arterial
- New York City Bus



Running Energy: Light-Duty Data Sources

(post QA/QC and filtering)

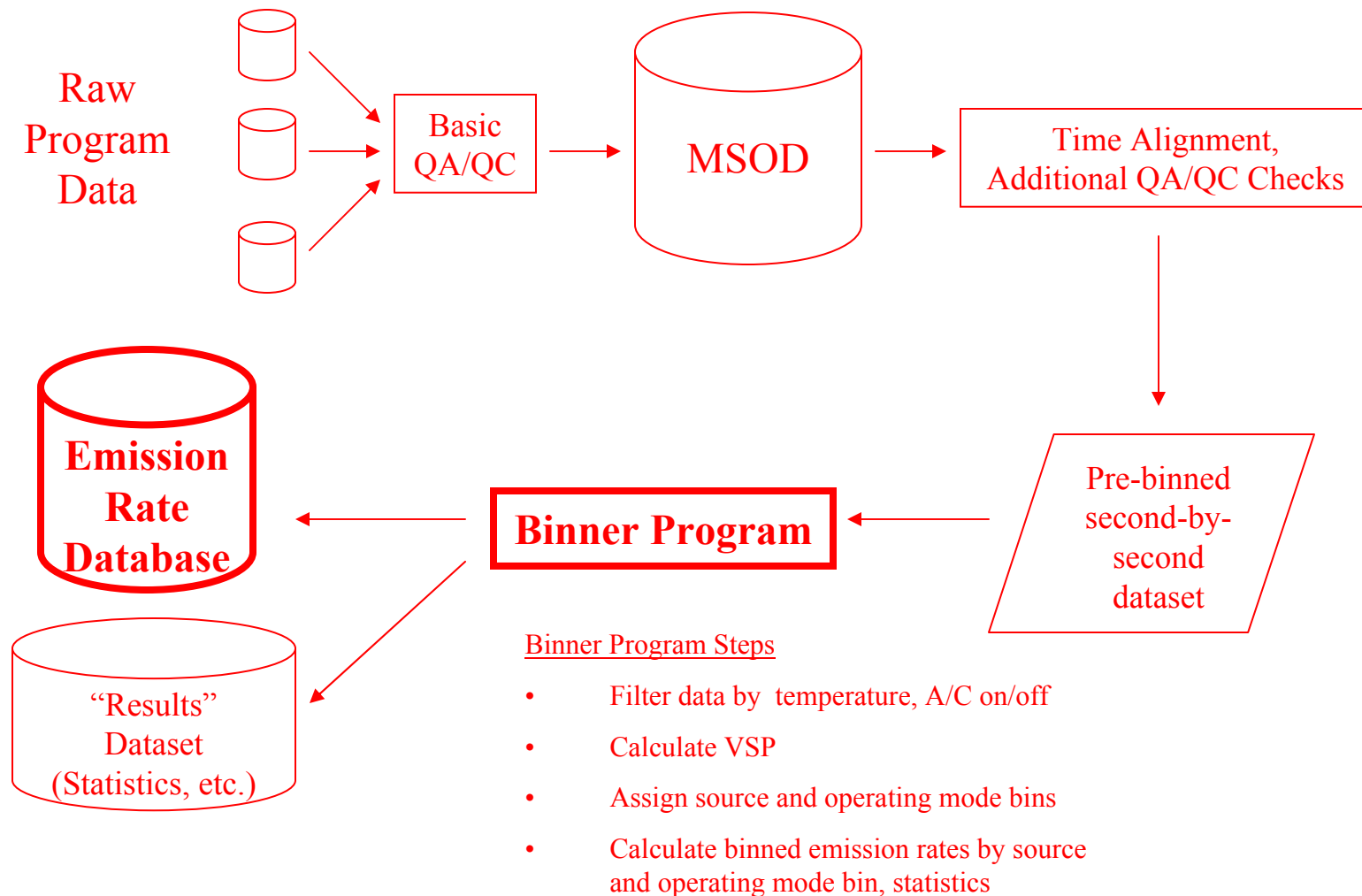
Source	Vehicles	Seconds	%
New York (IPA)	9900	5,720,688	51
EPA	464	3,306,562	29
UC Riverside	372	1,193,066	11
CRC (E-42/47)	12	582,122	5
ARB	42	487,112	4
TOTAL	10,790	11,289,550	

Running Energy: Heavy-Duty Data Sources

(post QA/QC and filtering)

Source	Vehicles	Seconds	%
EPA (LHDT)	92	1,728,869	43
West Virginia U	149	1,554,281	39
CRC (E-55/59)	25	472,155	12
New York	35	256,303	6
TOTAL	301	4,011,608	

Binning Process (Running Total Energy)



Binner Results

- **Percent of 1999 fleet covered by data in MSOD, by source use type:**

Passenger car: 98%

Passenger truck: 93%

Light commercial truck: 87%

Single Unit Short-haul: 65%

Single Unit Long-haul: 65%

Refuse Truck: 86%

Motorhome: 58%

Combination Short-haul: 36%

Combination Long-haul: 24%

Transit bus: 99%

School bus: 84%

Interstate bus: 100%

Motorcycles: 0%

Hole Filling with PERE

- Holes ranked by prevalence in the fleet
- PERE used to fill highest ranking holes
 - Rule of thumb: fill holes needed to bring coverage of each source type up to 95% of the fleet and/or representing at least 2% of the source type
- Focus:
 - Heaviest diesel trucks (>60K lbs)
 - Diesel and gas medium trucks
 - Motorcycles
- PERE run using average values within a source bin; results binned by operating mode

Hole Filling with Interpolation/Copying

- Low ranking holes filled by interpolation or copying of neighbor bins
- Bins to use for interpolation or copying determined by elaborate decision logic
 - See Appendix D of Energy & Emission Report
- SAS program written to performed this task

Hole Filling Lessons Learned

- **Define source bins and operating mode bins to minimize holes!**
 - The fewer the holes, the more straightforward the emission rate development process
- **MOVES design allows flexibility in these definitions, so they can be revisited as new data becomes available**

Start Energy Rates

- **As in MOBILE6, “start” defined as incremental emissions from a start event**
 - Start Rate (KJ/start) = Bag 1 – Bag 3
- **FTP bag data from MSOD**
 - 18,676 tests on 10,422 vehicles
- **Same source bins as for running energy; no operating mode bins**
 - Soak time not accounted for with energy, planned for criteria pollutants in MOVES2006
- **Hole filling necessary mostly for heavy-duty and/or diesel vehicles**

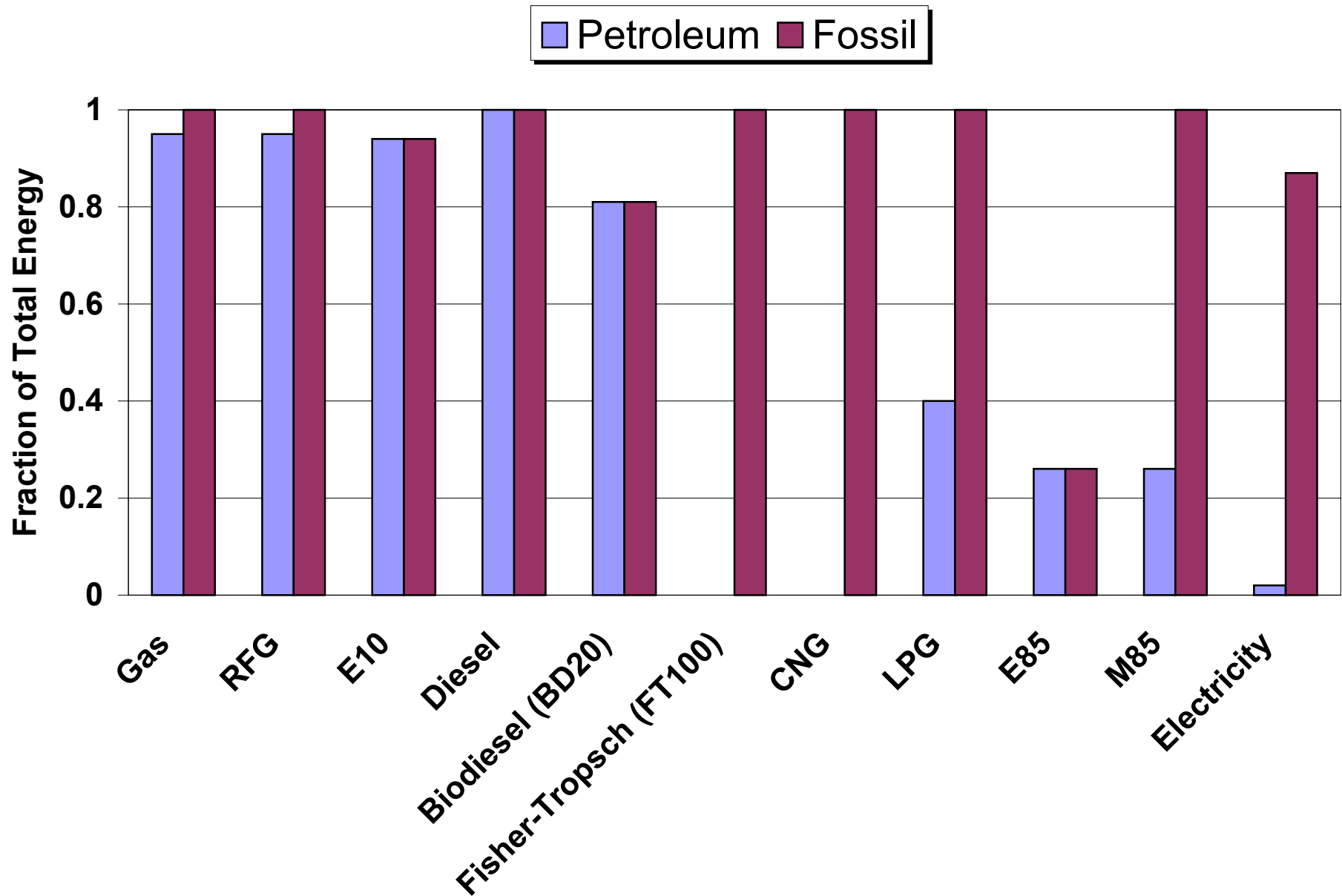
Extended Idle Energy Rates

- Not enough extended idle data to bin directly
- Relied on EPA study of 5 heavy-duty trucks
 - Lim, H. SAE 2003-01-0290
 - Tests @ 600 rpm and 1200 rpm idle (typical curb & extended)
- Increase in fuel consumption = **220%**
- Methodology for developing MOVES rates:
 - Multiply running idle rates by 2.22 for source bins \geq 30K lbs
 - Use running idle rates for source bins $<$ 30K lbs
- Activity data only in MOVES2004 for combination long-haul trucks

Petroleum & Fossil Energy

- **Calculated from Total Energy within MOVES**
 - No “rates” in emission rate database table
- **Petroleum and Fossil ratios derived from GREET**
- **Contained in FuelSubType database table**

Petroleum and Fossil Fractions



CH₄ and N₂O Rates

- **Analysis performed by ICF, Inc.**
 - Browning, L., *Update of Methane and Nitrous Oxide Emission Factors for On-Highway Vehicles*, EPA Report 420-P-04-016
- **FTP bag data from MSOD**
 - CH₄: 13,277 FTP tests on 6,950 vehicles
 - N₂O: 95 FTP tests on 64 vehicles
 - Includes new data from ARB and CE-CERT
- **Running: gram/hour of operation (not binned)**
- **Start: gram/start**
- **Hole filling for HD and/or diesel vehicles**
 - Used CO₂ ratio method

Source Bin Fields for CH₄ and N₂O Rates

Fuel Type	Engine Technology	Model Year Group	Regulatory Class
Gas	Conventional IC (CIC)	1972 and earlier	Motorcycle
Diesel	Advanced IC (AIC)	1973	Light Duty Vehicle
CNG	Moderate Hybrid - CIC	1974	Light Duty Truck
LPG	Full Hybrid - CIC	.	Heavy Duty Vehicle
Ethanol (E85)	Moderate Hybrid - AIC	.	
Methanol (E85)	Full Hybrid - AIC	.	
Gas H ₂	Fuel Cell	.	
Liquid H ₂	Hybrid - Fuel Cell	1999	
Electric		2000	
		2001-2010	
		2011-2020	
		2021-2050	

Advanced Technology Rates (2001 – 2010 model years)

- **Generated by Future Emission Rate Creator (FERC)**
- **Based on ratios to 2001-2010 Conventional IC**
 - Ratios contained in “ShortTermFERC” file
- **Ratios vary by technology, pollutant, process and operating mode (for total energy)**
 - Do NOT vary by source type, weight, or displacement
- **Ratio sources:**
 - Running energy: PERE (advanced technologies) or GREET (alternative fuels)
 - Start energy: scaled based on engine size for hybrids, same as running for other technologies
 - CH₄ and N₂O: generally the same as energy

Advanced Technologies in MOVES

 = to be added later

	Conventional Internal Comb	Advanced Internal Comb	Moderate Hybrid	Full Hybrid	Fuel Cell	Fuel Cell - Hybrid
Gas	X	X	X	X		
Diesel	X	X	X	X		
CNG	X					
E85	X					
M85	X					
LPG	X					
Electric						
Gas H ₂		X			X	X
Liquid H ₂					X	X

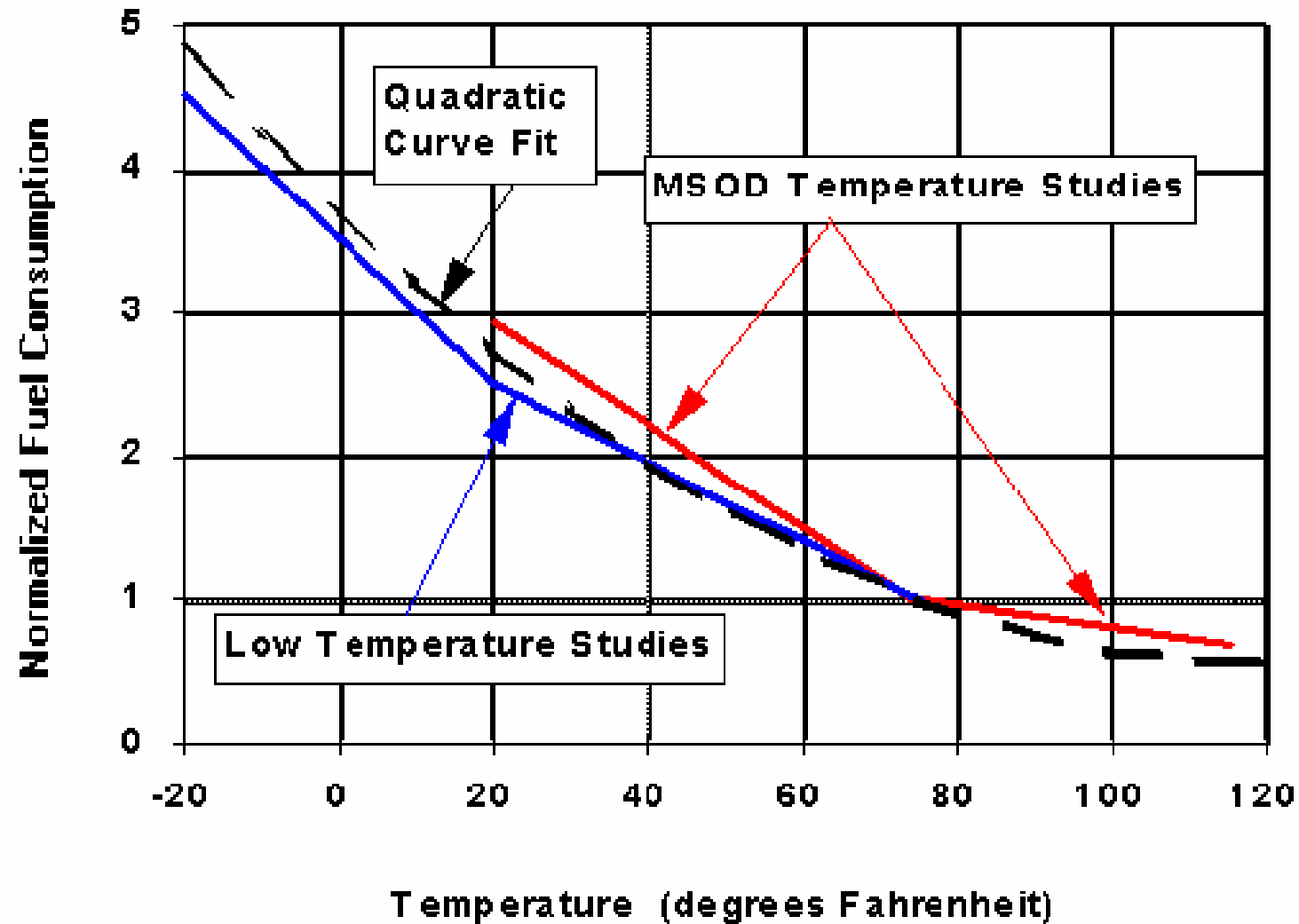
Long Term Future Rates (2011 and later model years)

- **Generated by Future Emission Rate Creator (FERC)**
- **Based on ratios to 2001-2010 rates by technology**
 - Ratios contained in “LongTermFERC” file
- **Ratios vary by technology, pollutant, process**
 - Do NOT vary by operating mode, source type, weight, or displacement
- **For default case, all ratios set to 1**
 - i.e. no evolution assumed within a given technology
- **User can customize all advanced technology and future rates via FERC**

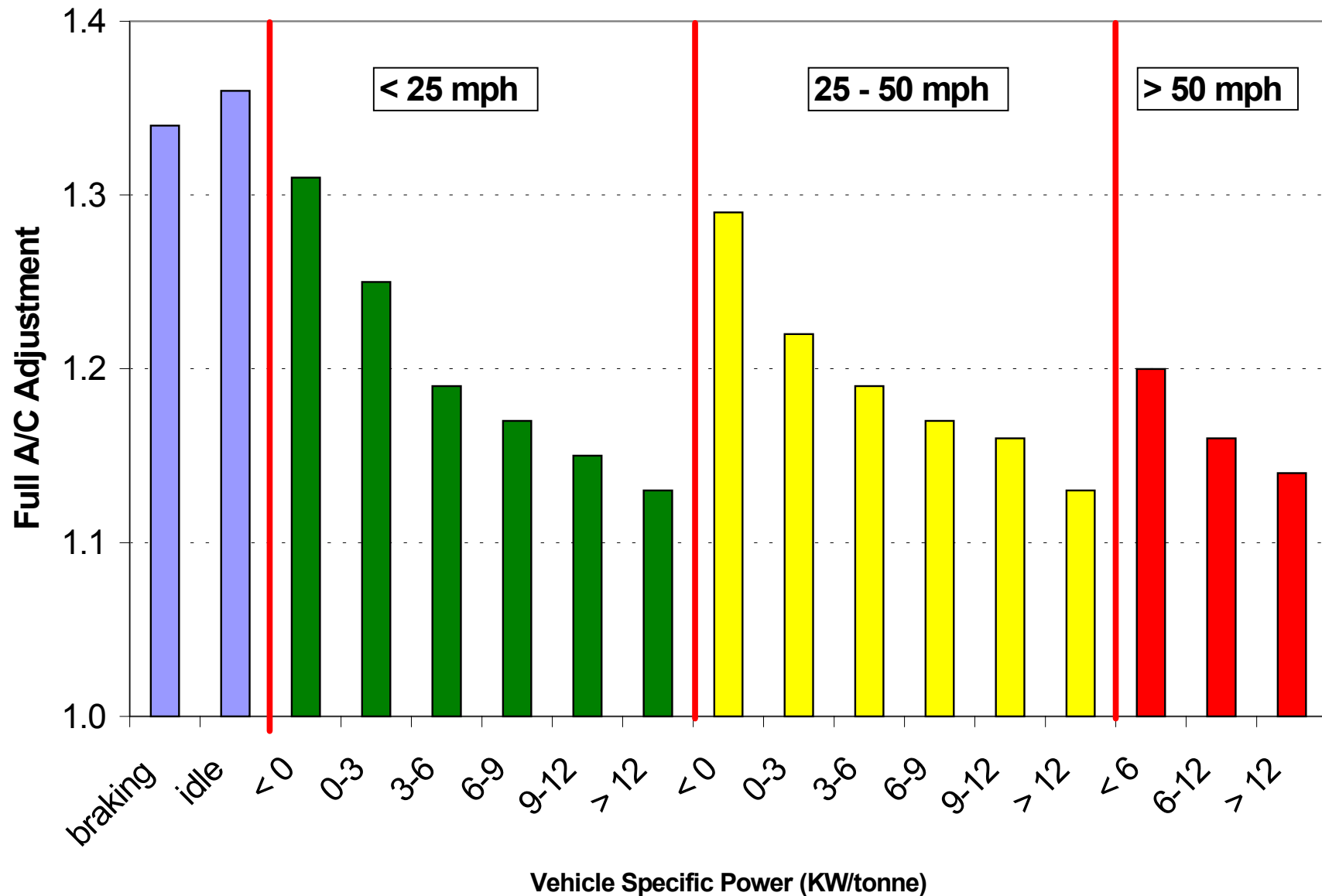
Adjustments

- **Temperature**
 - Start energy only
 - 580 vehicles at multiple temperatures $\geq 20^{\circ}$ F
 - 9 vehicles at multiple temperatures $\geq -20^{\circ}$ F
- **Air Conditioning**
 - Running energy only
 - Based on MOBILE6 work
 - A/C demand as a function of Heat Index (20 vehicles)
 - A/C energy consumption by operating mode (38 vehicles)
- **Placeholders for Fuel, I/M**

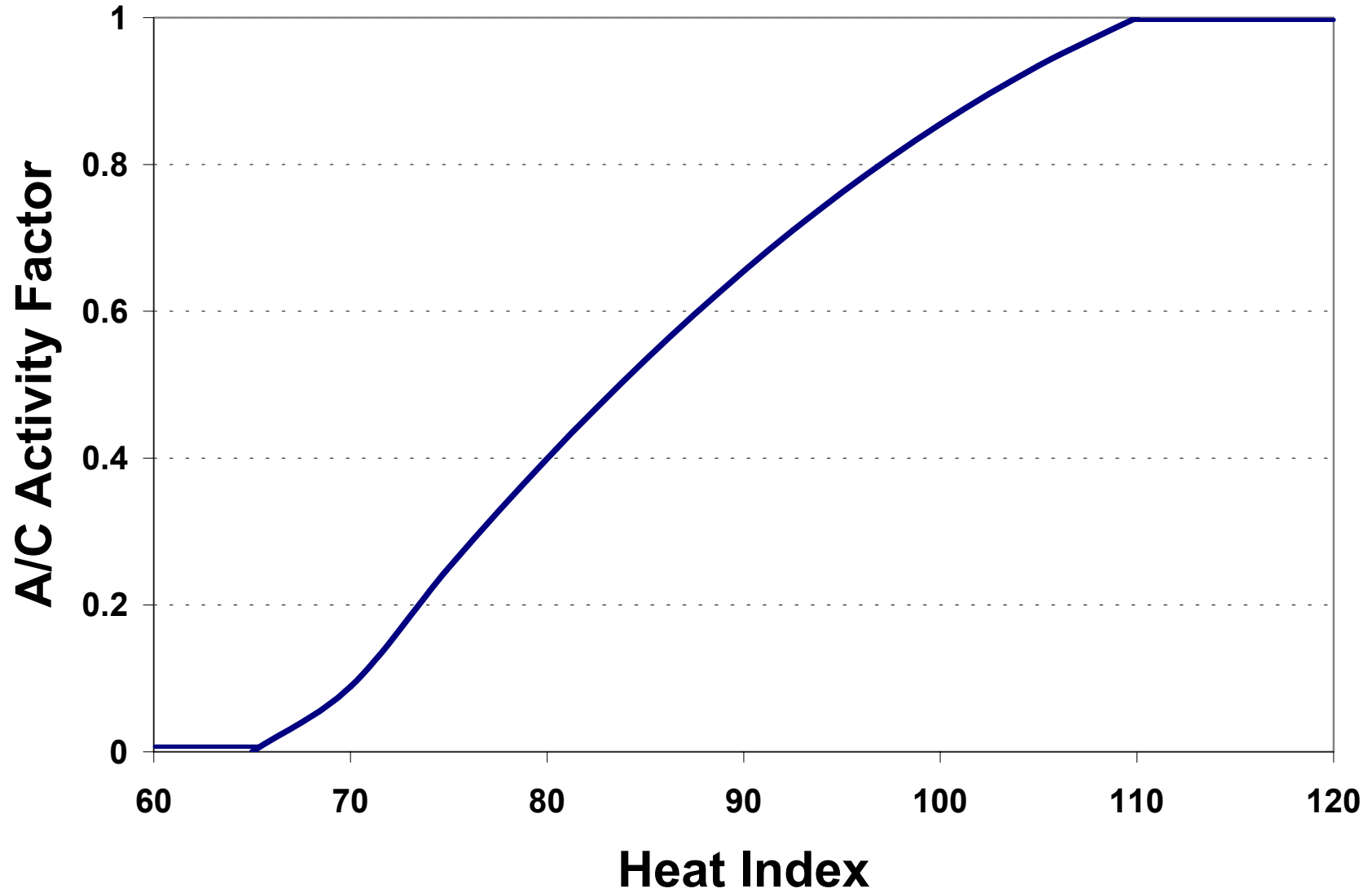
Start Energy Temperature Adjustment



Running Energy Full A/C Adjustment



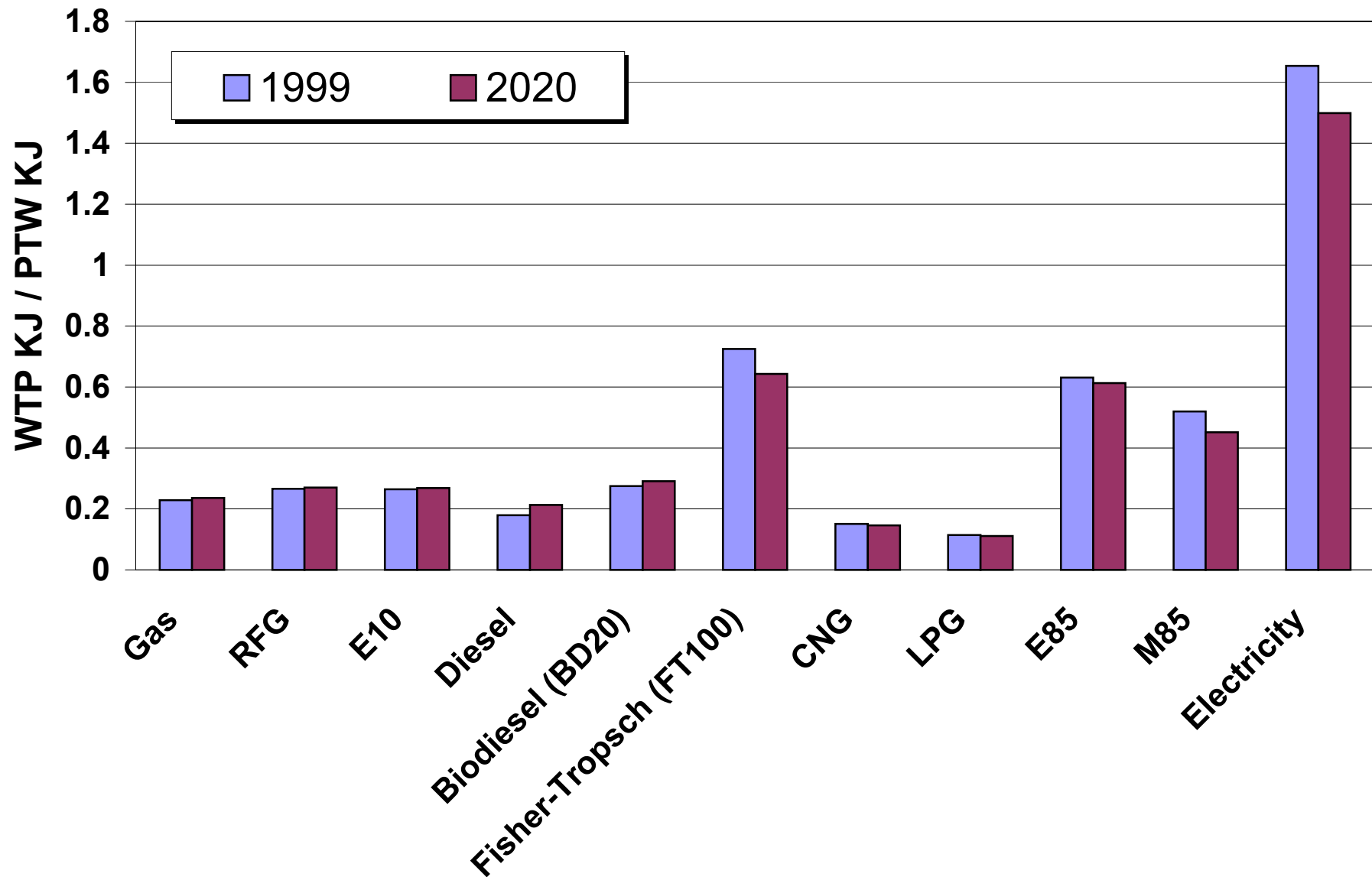
A/C Activity Factor



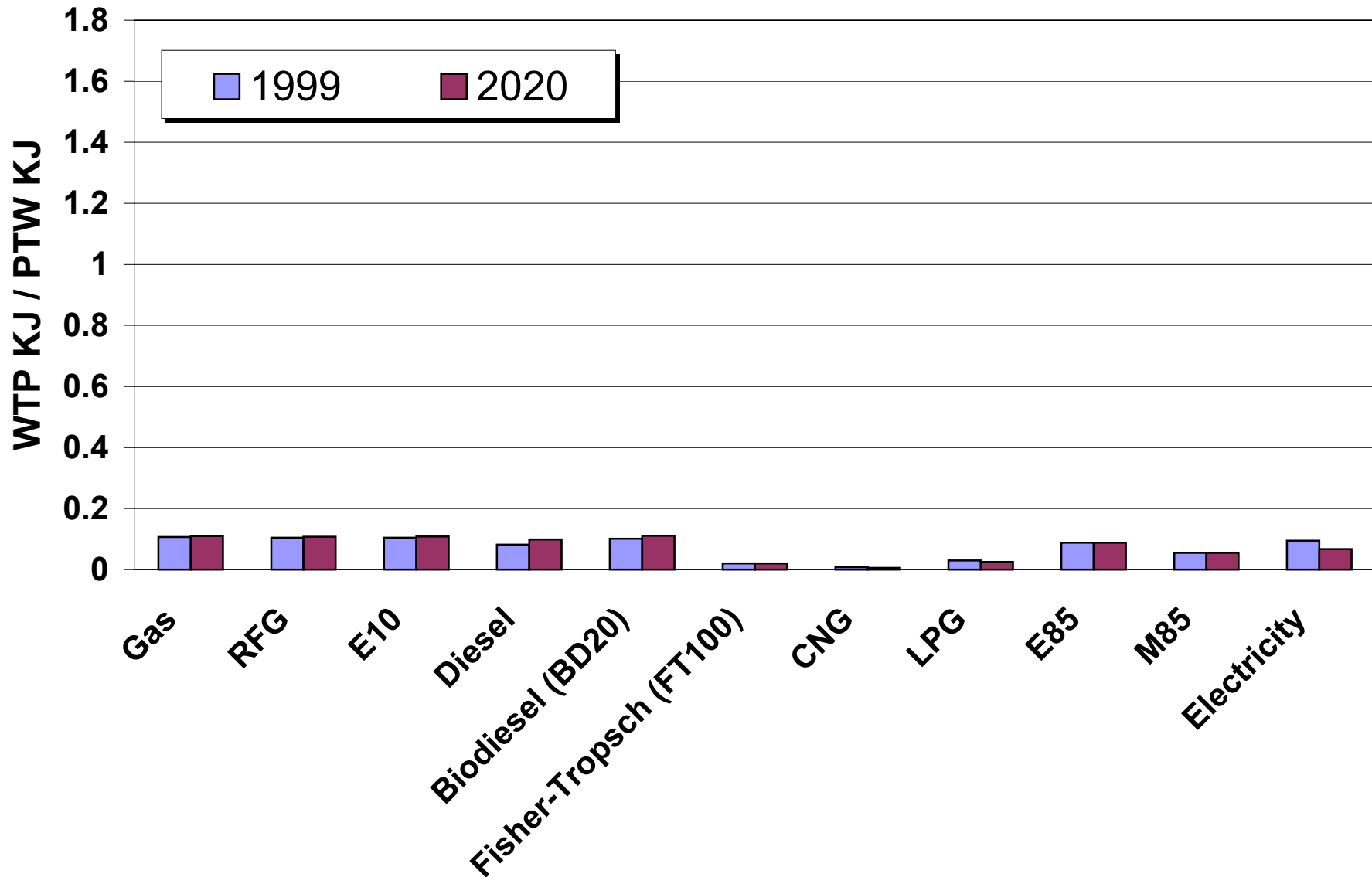
Well-To-Pump Rates

- **Generated by GREET via MOVES interface**
 - GREETWellToPump database table
 - GREET / MOVES interface allows easy update of rates
- **Rates expressed as WTP energy or emissions per PTW energy consumption**
- **Rates by:**
 - Calendar year (1999 through 2050)
 - Fuel: CG, RFG, E10, Diesel, Biodiesel, FT Diesel, Ethanol, Methanol, CNG, LPG, Electricity
 - Gaseous Hydrogen and Liquid Hydrogen to be updated, added to MOVES2004

Well-To-Pump Rates: Total Energy



Well-To-Pump Rates: Petroleum Energy



Summary

- Modal binning approach & binner program used for running total energy
- Wide variety of data sources used; data gaps required hole filling methods
- New CH₄ and N₂O rates developed
- Advanced technology rates developed from ratios to conventional technology
- Temperature and A/C adjustments included
- Well-To-Pump rates from GREET