Infrared-Excitation for Improving Hydrocarbon Fuels' Combustion Efficiency of Engines

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AUTOECO
RASSEGNA DELL'AUTOMOTIVE ECOLOGICO
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IR-Excited Fuel Technology

Contents:

Motivation: the demands

2007 SAE World Congress

Government:
- Air Quality
- Global Warming
- Energy Security

EMISSIONS REDUCTION

FUEL ECONOMY

Car Makers:
PROFITS

FUN TO DRIVE

Customers:
- Safety
- Comfort
- Horsepower
- Fuel Costs

Engineers:
- ICE Optimization/ Aftertreatment
- Aerodynamics
- Weight Reductions

need Physics, Magic, or Miracle?

Introduction

Approach:

IR-excitation to improve fuel combustion efficiency

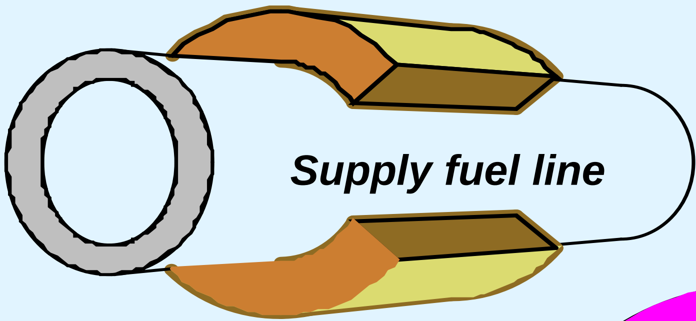
Known Scientific Facts:

- **Organic Chemistry**
  - **HC molecules are IR-active and absorb 3 – 14 μm IR photons causing vibrations**
- **Photoselective Chemistry**
  - **Increasing reactant vibrational energy is most effective at promoting reaction.**

Known IR-Technology:

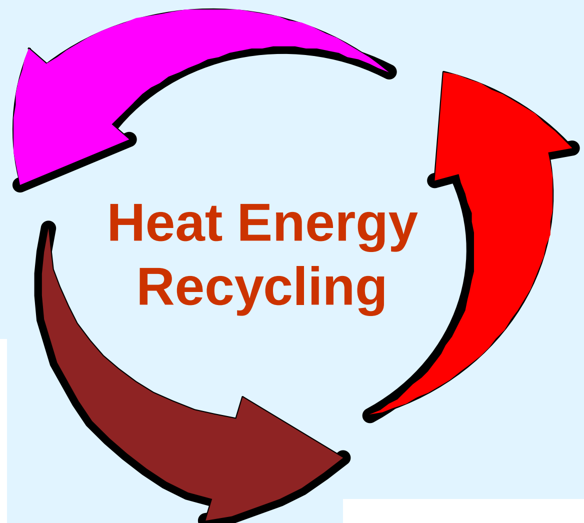
- **IR-emitters for agricultural applications (Japan)**

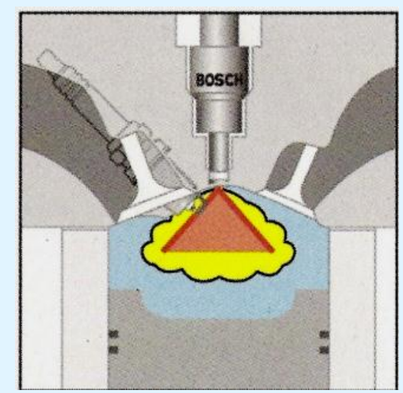
The Innovative Concept



IR-emitter

Step 1: IR-emitter absorbs radiation heat from engine





Efficient combustion

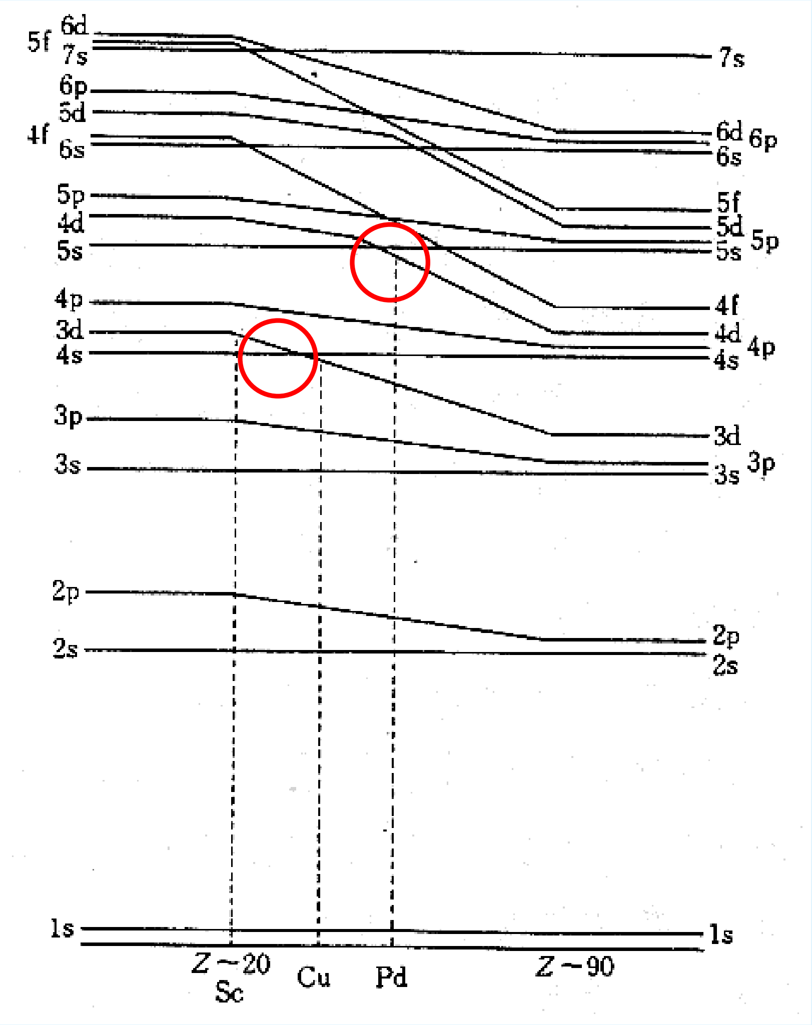
Step 2: IR-emitter emits 3 – 14 µm IR photons

Step 3: IR photons excite HC-molecules in the fuel

Transition Metal Oxides

Constituent electrons are thermally agitated to higher levels;

Excited electrons return to initial levels by emitting IR photons in 3 - 14 μm wavelengths



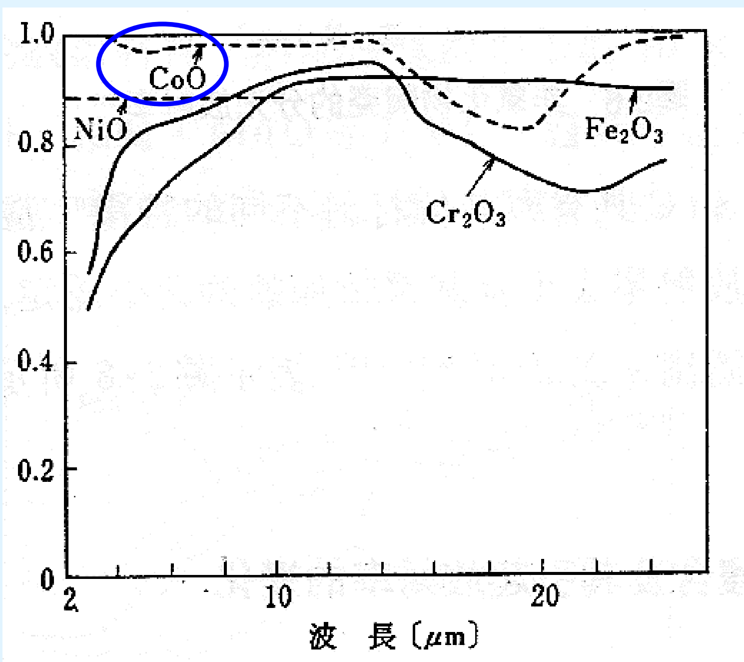
Transition Metals

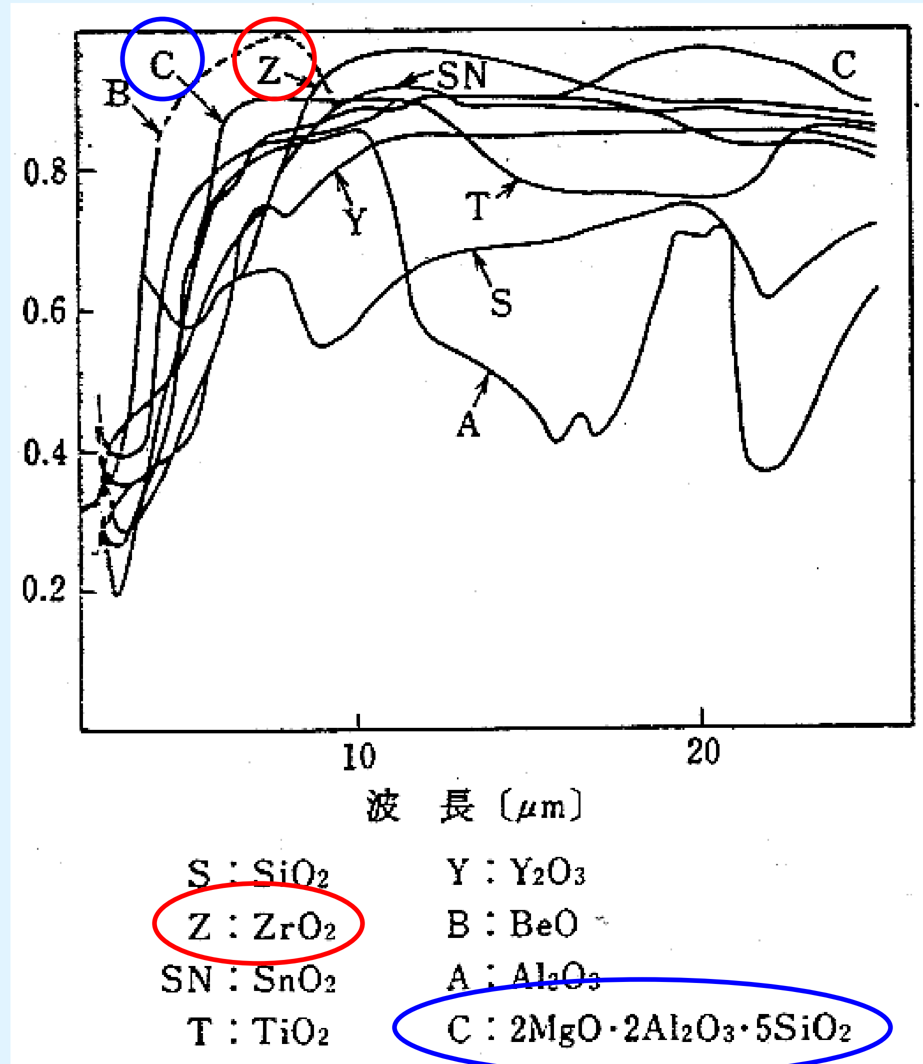
Ti: $3d^2\ 4s^2$ (22)
Cr: $3d^5\ 4s^1$ (24)
Co: $3d^7\ 4s^2$ (27)
Ni: $3d^8\ 4s^2$ (28)
Zr: $4d^2\ 5s^2$ (40)

IR-Emitters

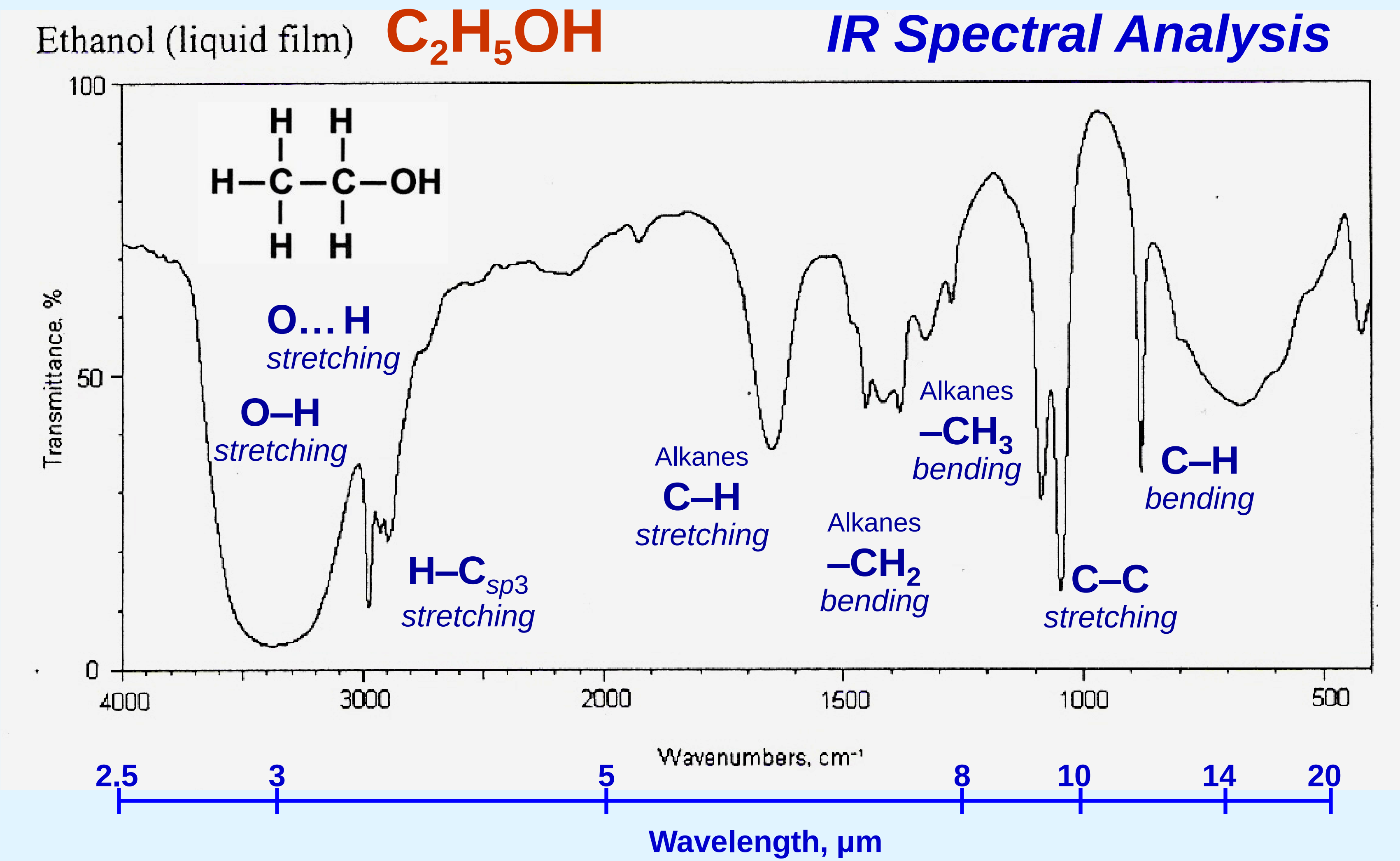
3 – 14 µm
mid-IR Emitter

8 – 20 µm
far-IR Emitter

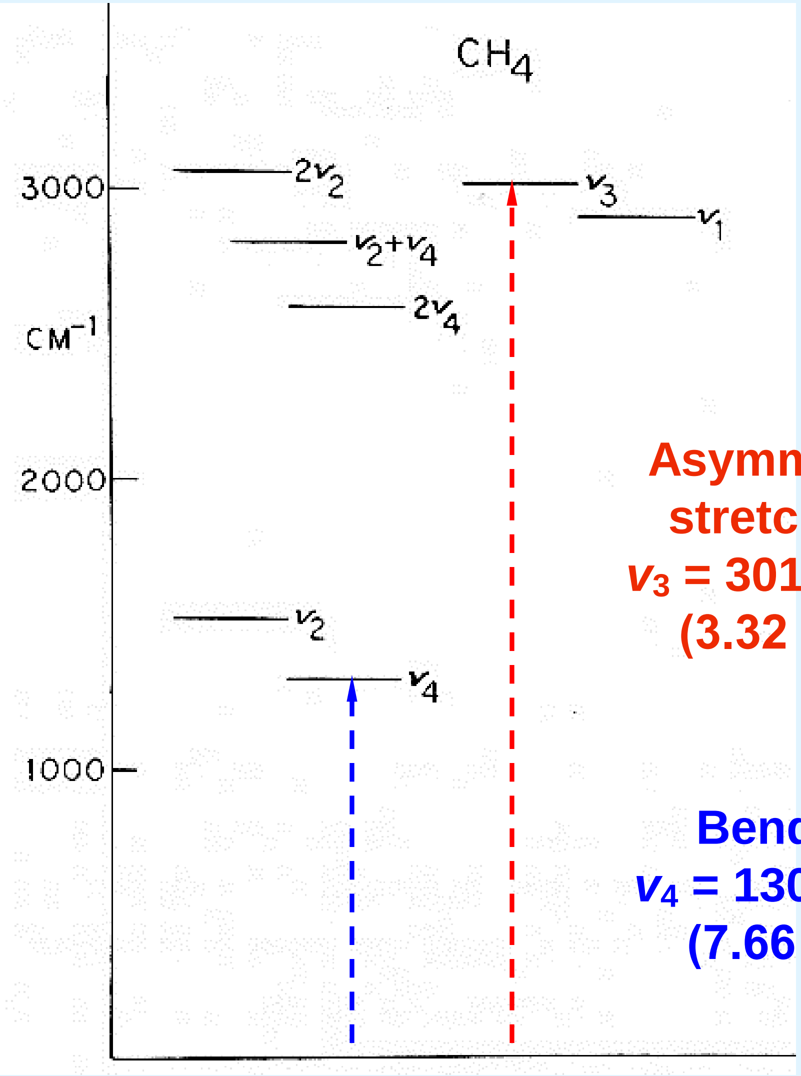




HC Molecules are IR-Active



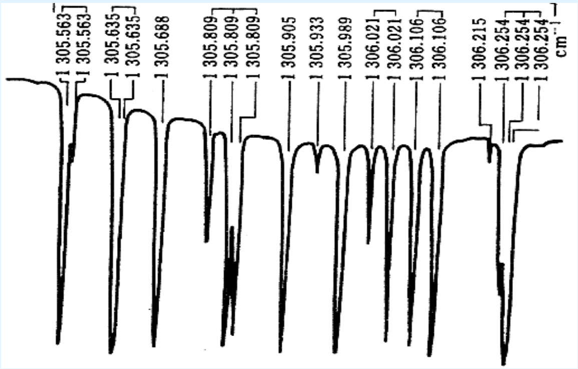
CH_4 Energy Level Diagram



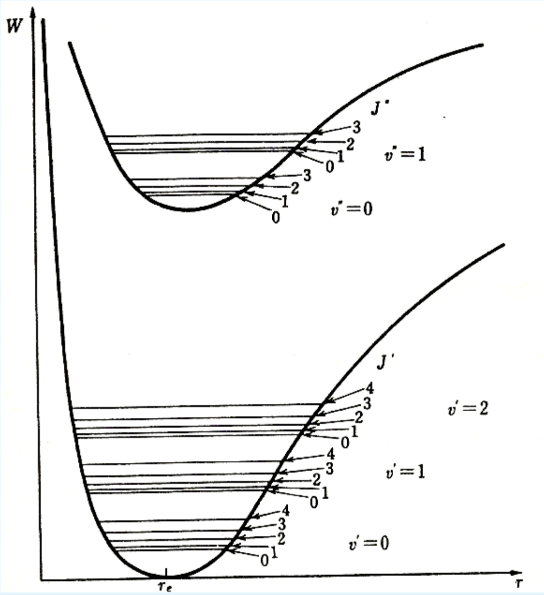
Asymmetric stretching
ν_3 = 3012 cm^{-1}
(3.32 μm)

Bending
ν_4 = 1305 cm^{-1}
(7.66 μm)

1305.563 **1306.264**



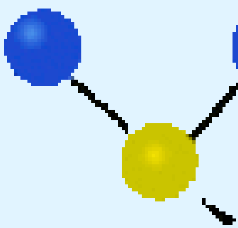
Resonance modes at
ν_4 = 1305 cm^{-1}



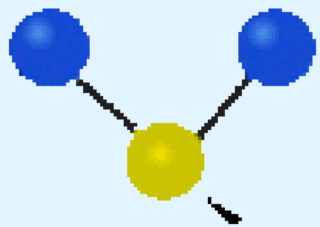
Molecular Vibrations

Molecules vibrate in 6 ways

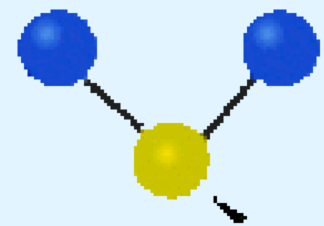
Symmetrical Stretching



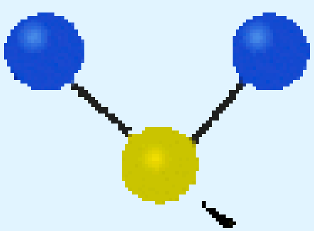
Antisymmetrical Stretching



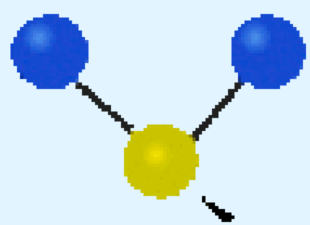
Scissoring



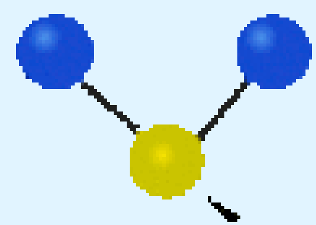
Rocking



Wagging

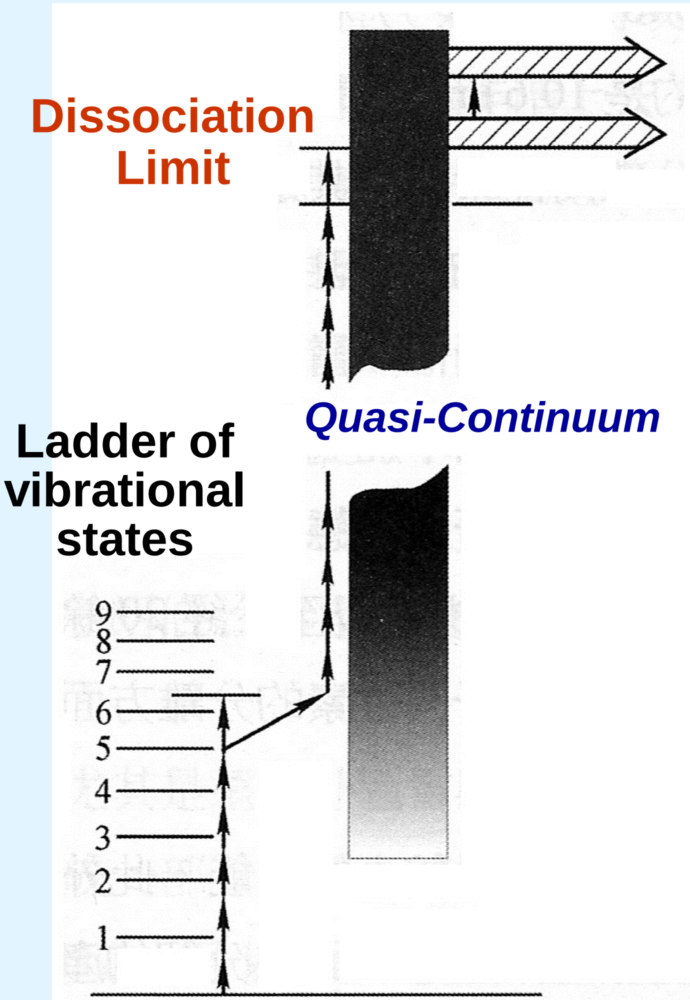


Twisting



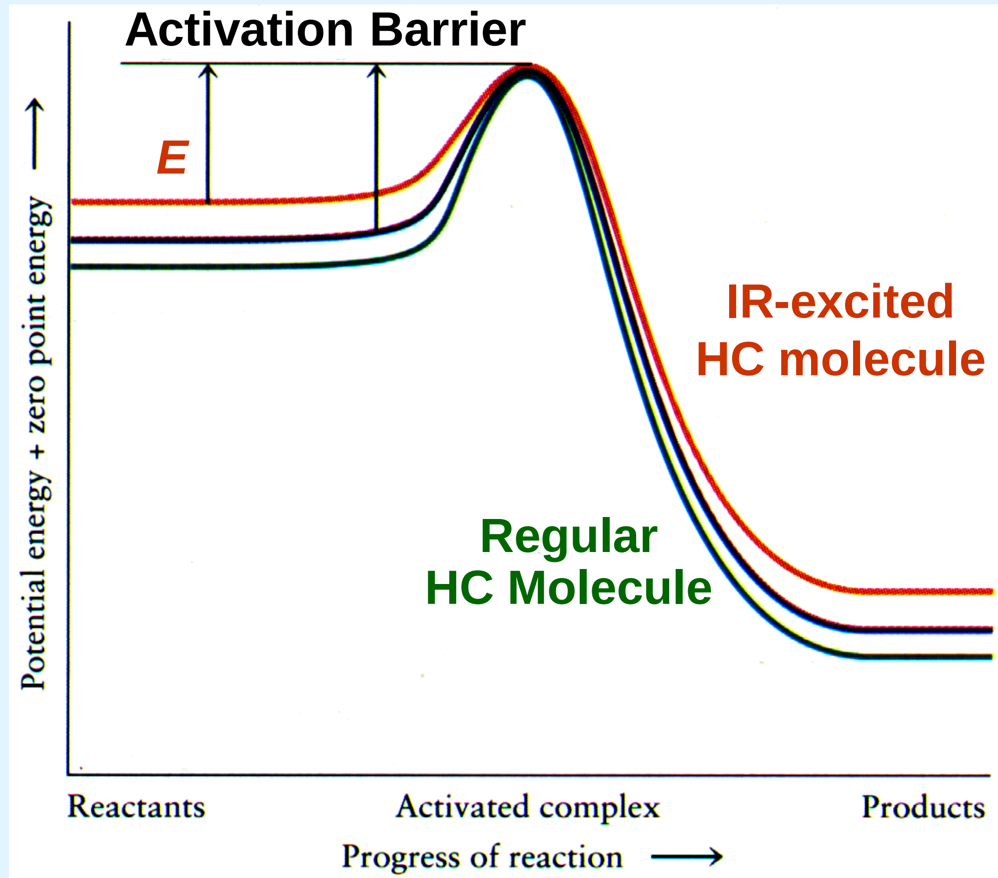
Vibrational States

Multi-photons absorption & excitation



Reaction Rate:

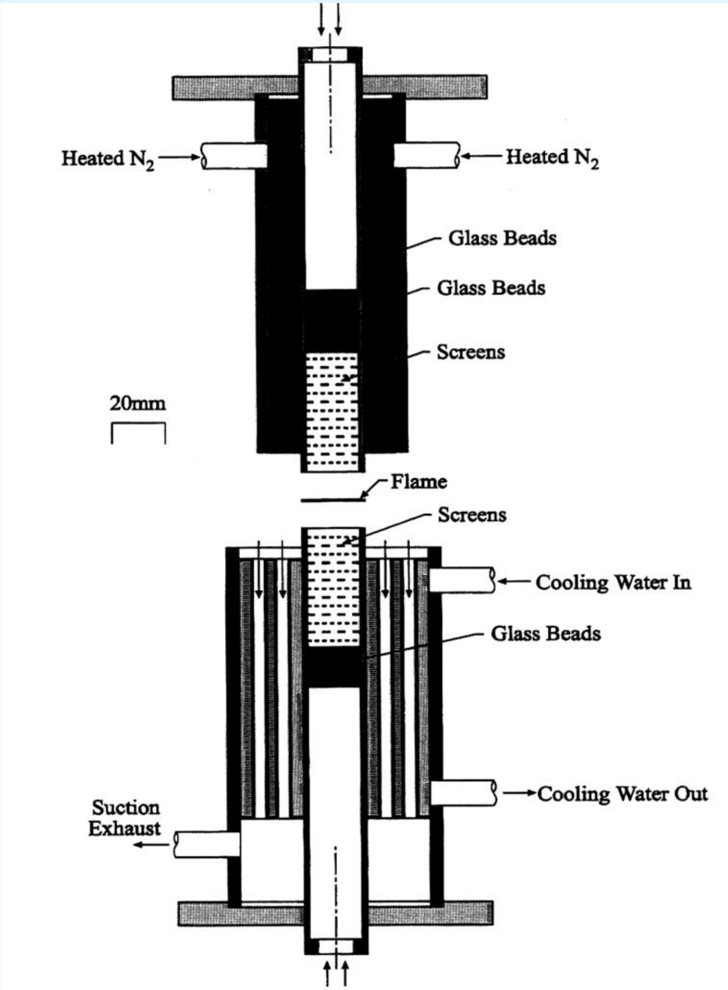
$$W = k\, e^{-E/RT}$$



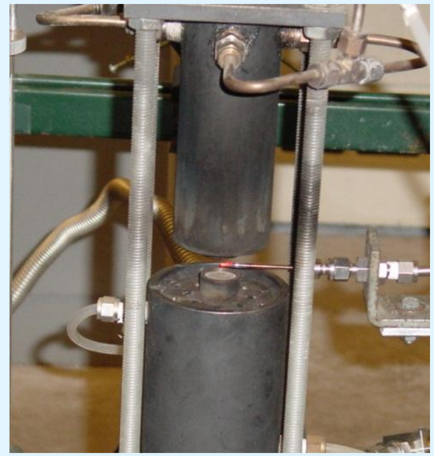
Proof of Underlying Science

Methane-Air Counter-flow Flame Experiment

Air



Methane

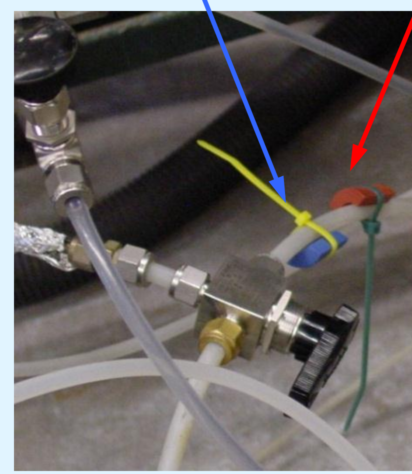


Purdue University

mid-IR emitter

Far-IR emitter

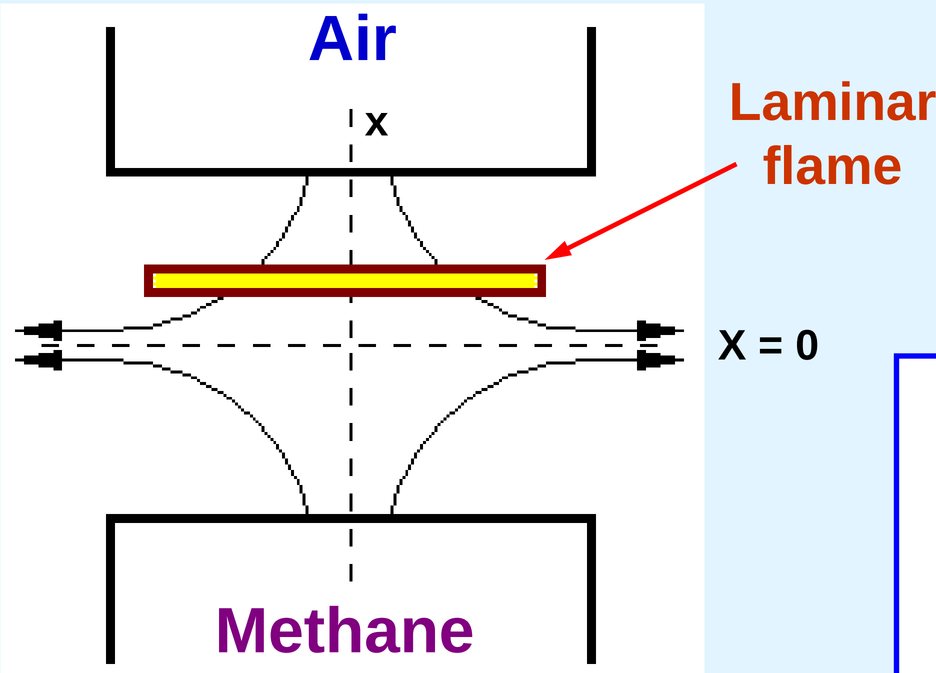
Path 2



Path 1

Path 1: Regular
Path 2: IR-excited

Laminar Diffusion Flame



$$CH_4 + O_2 \rightarrow CO + H_2 + H_2O$$

$\quad \rightarrow H_2 + \frac{1}{2}\, O_2 \rightarrow H_2O$

$\quad \rightarrow CO + \frac{1}{2}\, O_2 \rightarrow CO_2$

Methane combustion chain reaction:

$CH_4 + O \rightarrow CH_3 + OH$

$O_2 + CH_3 \rightarrow CH_3OO$

$CH_4 + CH_3OO \rightarrow CH_3 + CH_3OOH$

$CH_3OOH \rightarrow CO + 2\, H_2 + O$

$2\, CH_4 + O_2 \rightarrow 2\, CO + 4\, H_2$

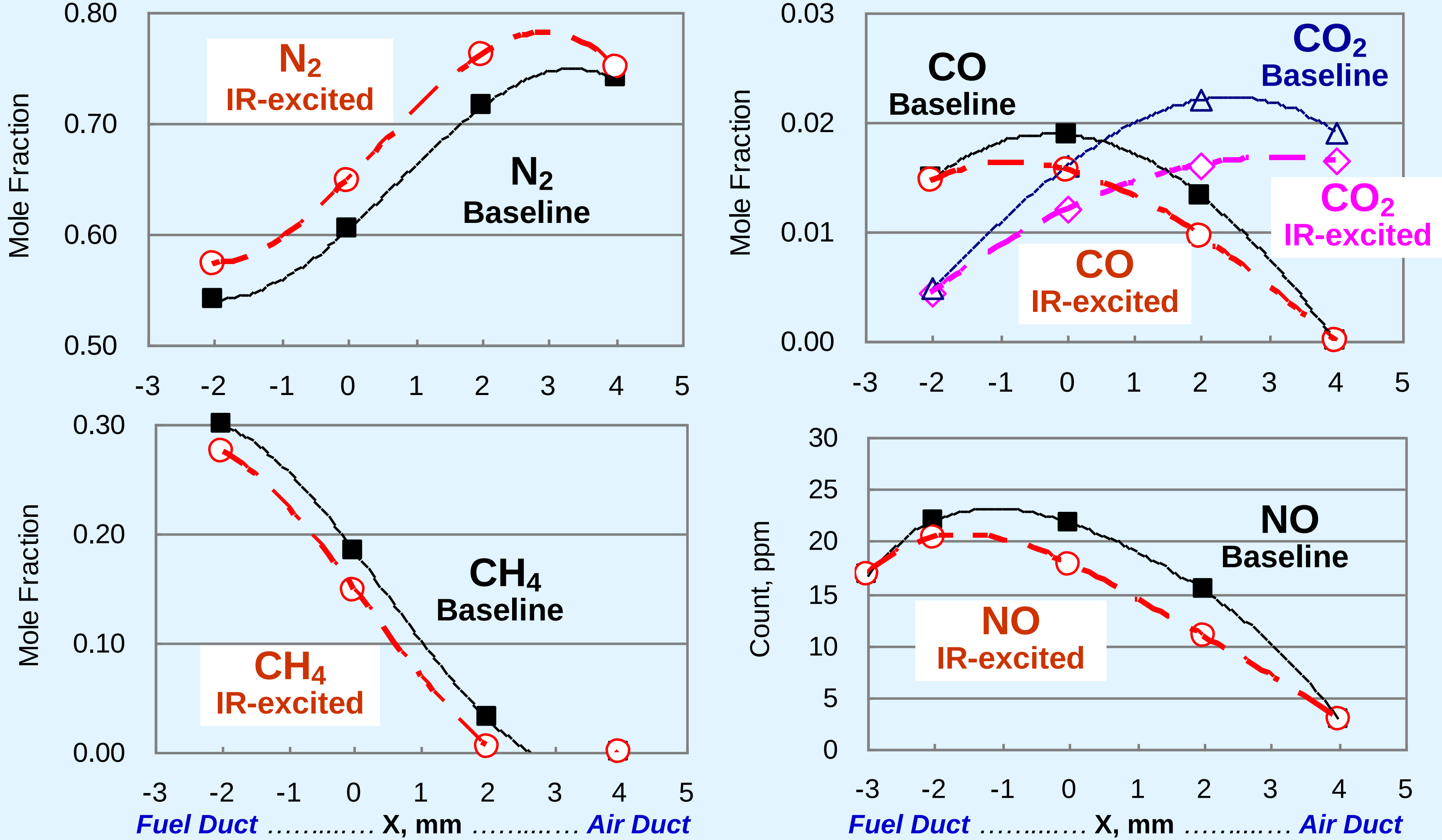
$CO + OH \rightarrow H + CO_2$

$O_2 + CO + H \rightarrow OH + CO_2$

$H_2 + OH \rightarrow H + H_2O$

$O_2 + H_2 + H \rightarrow OH + H_2O$

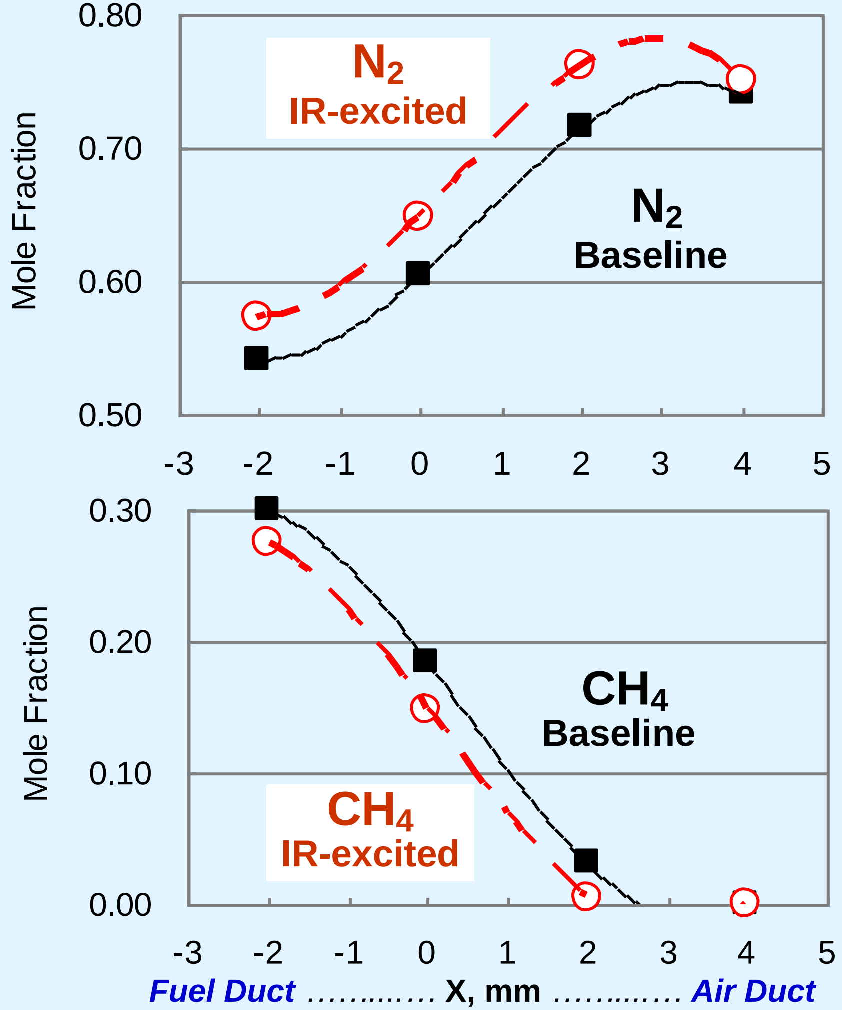
Experimental Results



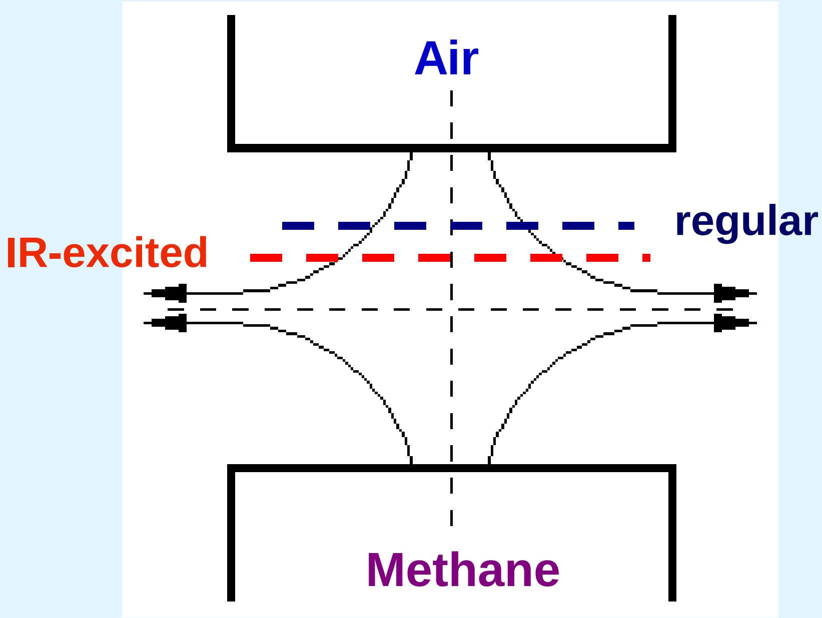
Flame occurs faster

Less CO, CO_2 & NO emissions

Observation (1): faster burn



Flame occurs faster



IR-excited fuel:

- more combustible
- burns faster, more completely
- reduced flame strain rate
- reduced fuel flow momentum
- flame is pushed downward

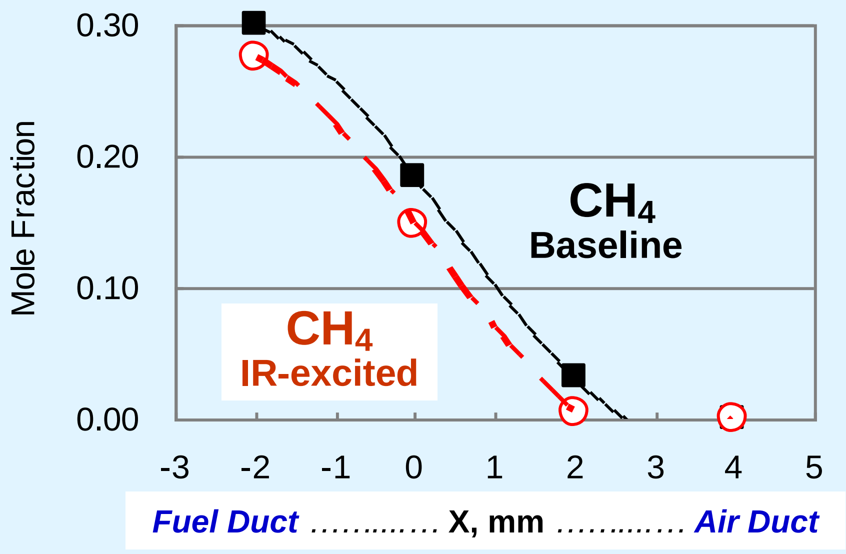
Observation (2): Less Fuel

Fuel Consumption Rate

$$Fuel\ Consumption\ Rate = \int_0^L \varpi_{CH4}\, dx$$

L: distance between the ducts (15 mm)

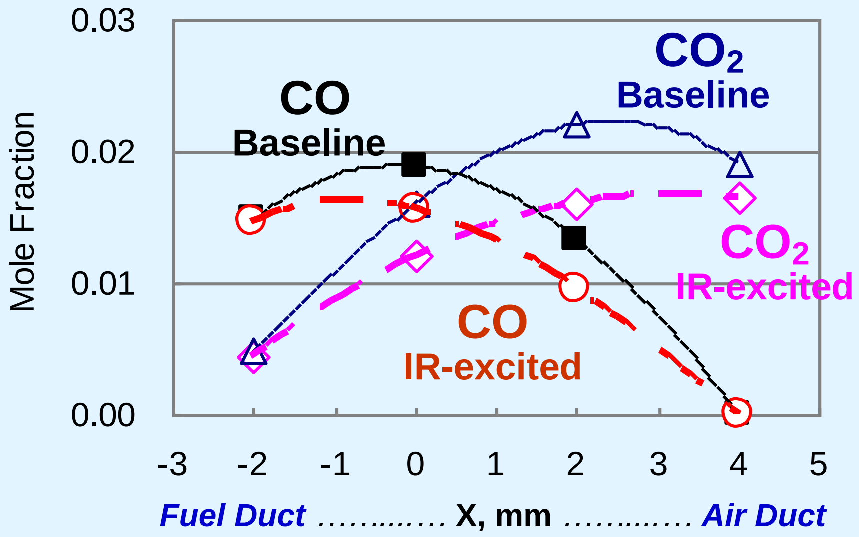
ω_{CH4} : volumetric consumption rate, moles/cm^3/sec



IR-excited fuel:

Fuel Consumption Rate is computed to be 8% less.

Observation (3): Less CO



Methane combustion chain reaction:

$CH_4 + O \rightarrow CH_3 + OH$

$O_2 + CH_3 \rightarrow CH_3OO$

$CH_4 + CH_3OO \rightarrow CH_3 + CH_3OOH$

$CH_3OOH \rightarrow CO + 2\,H_2 + O$

$2\,CH_4 + O_2 \rightarrow 2\,CO + 4\,H_2$

CO is a precursor of CO_2

$H_2 + ½\,O_2 \rightarrow H_2O$

$CH_4 + O_2 \rightarrow CO + H_2 + H_2O$

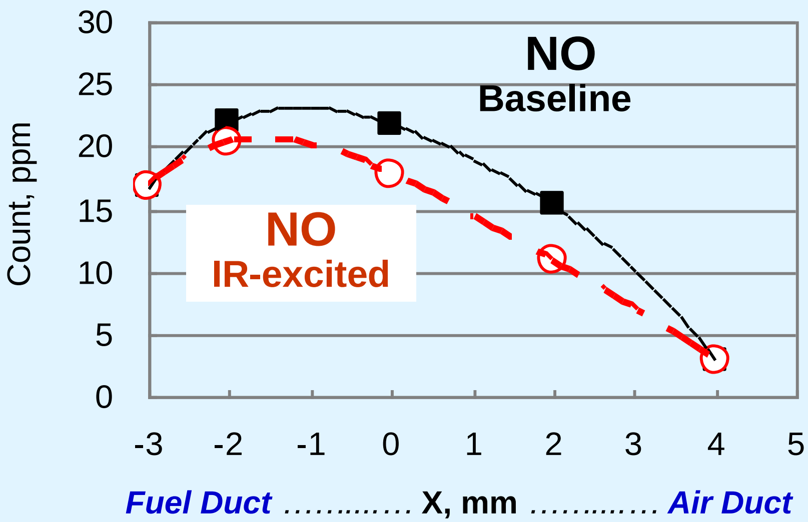
$CO + ½\,O_2 \rightarrow CO_2$

IR-excited fuel:

Combusts faster and more completely;

CO & CO_2 emissions are computed to be 25% less.

Observation (4): Less NO



EIJ*, emission index for specie *J

$$EIJ = \frac{\int_0^L M_J \varpi_J \, dx}{\int_0^L M_{CH4} \varpi_{CH4} \, dx}$$

Mj : molecular weight
ωJ : volumetric production rate

Less NO emissions:

Thermal NO formation follows fuel combustion; with a faster combustion, there was less time for NO to form.

IR-excited fuel:

Emission index of NO is computed to be 15% less.

Summary of Observations

IR-excitation makes methane combust faster and more completely

- Less ***Fuel Consumption Rate***
- less CO and CO_2 emissions
- less NO emissions

The first scientific proof of IR-excited fuel technology

Proposed Engine Application

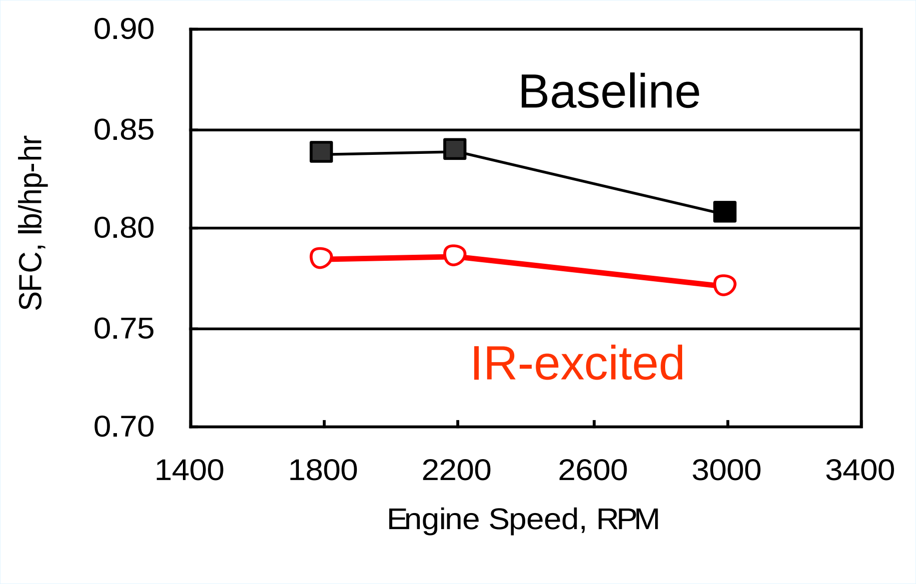
- IR-Emitters are retrofitted to supply fuel line, absorbing engine heat to emit IR photons.
- HC molecules traversing thru the fuel line are excited, raising vibrational states to lower activation barrier and increase combustibility.
- IR-excited fuel burns faster in cylinders, allocating more heat to do work and less heat loss to raise exhaust gas temperature (EGT).
- Increased power, with lower specific fuel combustion and less HC, CO, NOx, and CO_2 emissions.

GM Quad-4 Gasoline Engine

at Engine Lab, Purdue University

Specific Fuel Consumption (unit: lb/hp-hr)

RPM	1800	2200	3000
Baseline	0.8369	0.8381	0.8072
w/FIR	0.7839	0.7852	0.7693
Change	- 6.76%	- 6.74%	- 4.93%



CO & NO Emissions Test

at Engine Lab, Purdue University

PowerTek

Single Cylinder Dynomometer

Fuel: Propane
Displacement: 13 cu in.
Gross power: 7.5 HP
Gross torque: 10 ft.lb

CO Measurement (ppm) average reduced 14.5%

Speed, RPM	1500	2000	2500
Baseline	542	1051	1596
w/ IR-emitter	468	820	1472
Improvement	- 13.7 %	- 22.0 %	- 7.8 %

NO Measurement (ppm) average reduced 10.2%

Speed, RPM	1500	2000	2500
Baseline	254	95	37
w/ IR-emitter	247	79	33
Improvement	- 2.8 %	- 16.8 %	- 10.8 %

U.S. EPA Test

AutoResearch Lab, an EPA-recognized Lab

1998 Mercury Grand Marquis, V8, 4.6 L
at 16,300 odometer mileage (Jan. 1999)

FTP – Federal Test Procedure for City Driving

Test Item	HC	CO	NOx	CO_2	MPG
Baseline	0.208	2.709	0.362	520.74	16.98
with FIR	0.130	1.776	0.196	438.29	20.22
Change	- 37.5 %	- 34.4 %	- 45.9 %	- 15.8 %	+ 19.1 %

HFET – Highway Fuel Economy Test

Test Item	HC	CO	NOx	CO_2	MPG
Baseline	0.084	1.227	0.342	330.39	26.84
with FIR	0.069	0.993	0.280	281.41	31.52
Change	- 17.9 %	- 19.1 %	- 18.1%	- 14.8 %	+ 17.4 %

Emissions: Diesel Pickup

Iveco Motor Co. (Nanjing, China)
4.2 Ton Light-Duty Pickup
4 cyl. 2.8 L Diesel Engine (max. 78 KW)
tested with a 60 Nm load

(a) NOx Emissions, ppm

Speed, km/h	30	40	50	60	Avg.
Baseline	642	567	505	431	
w/ IR-Emitter	598	530	463	410	
Change	- 6.8%	- 6.5%	- 8.3%	- 4.6%	- 6.6%

(b) Smoke Emissions, % Opacity

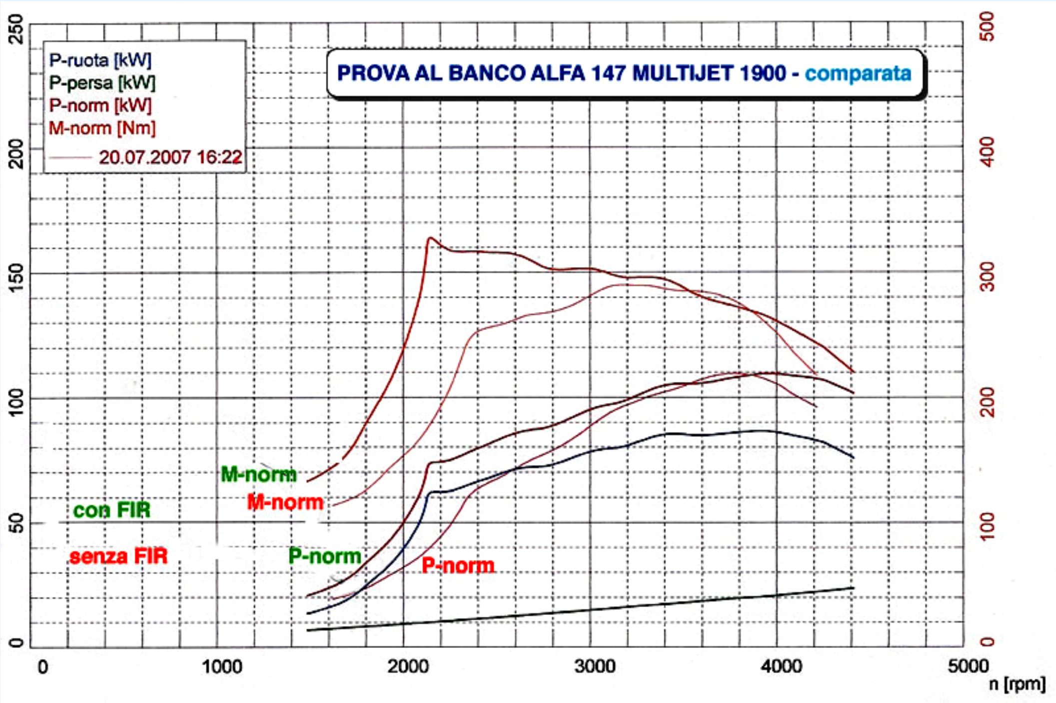
Speed, km/h	30	40	50	60	Avg.
Baseline	16.6	15.8	10.6	6.6	
w/ IR-Emitter	12.4	11.2	7.3	6.0	
Change	-25.3%	-29.1%	-31.1%	-9.1%	-23.7%

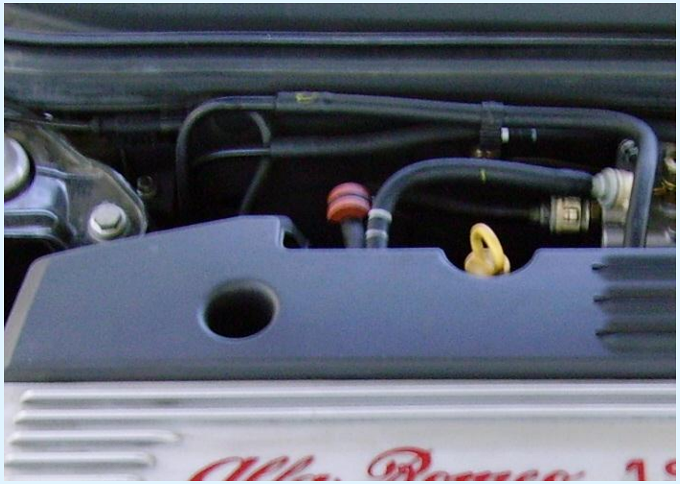
FIR helps reduce smoke and NOx simultaneously.

P-norm/M-norm Dyno Tests

CARBURATORI BERGAMO, 24127 (BG), ITALY 7/20/2007

2004 Alfa Romeo 147 JTD
1900 cc Multijet turbodiesel
4 cyl. 16v, 110 kW @4000 rpm
Odometer: 110,000 km



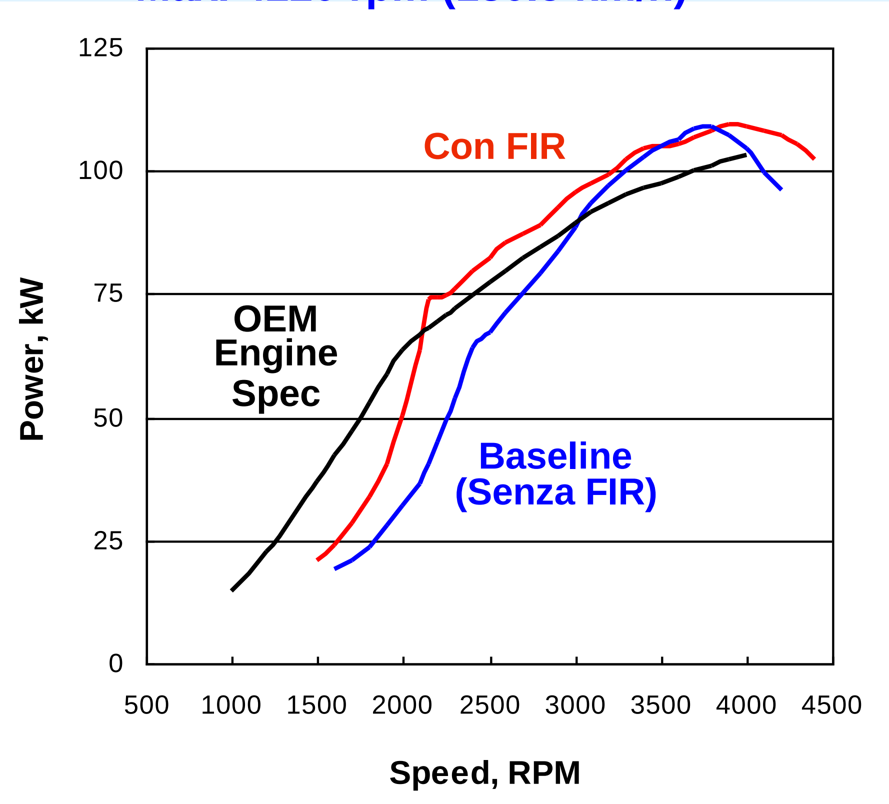


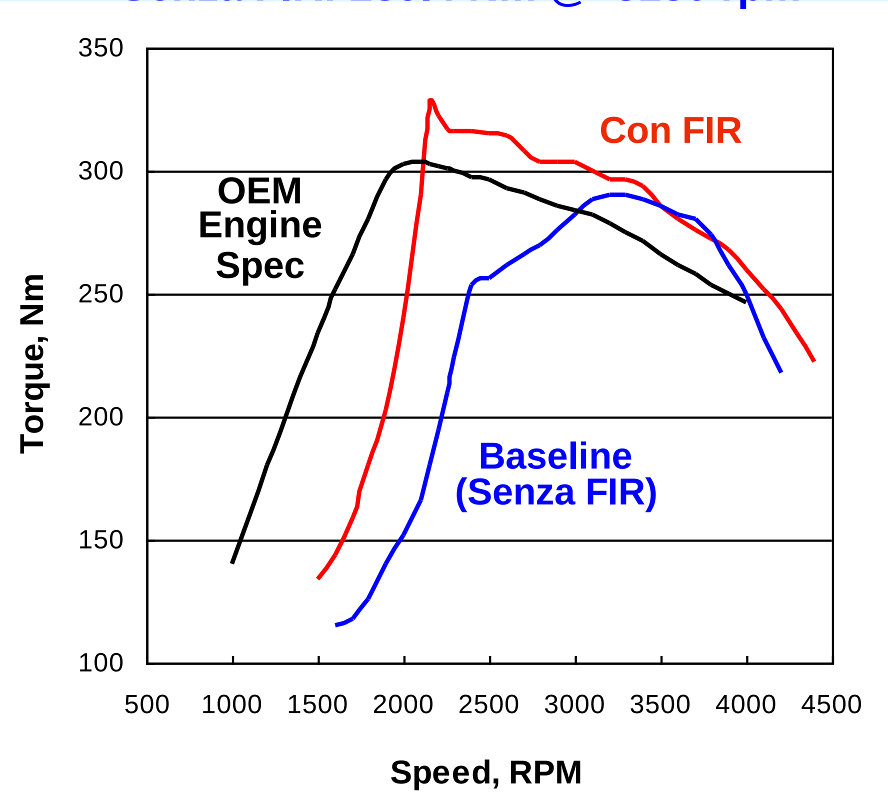
Power/Torque Measurement

Potenza & Coppia at 6th Gear (ratio 0.614:1)

2004 Alfa Romeo 147 JTD
Max. 4410 rpm (149.0 km/h)
Max. 4220 rpm (130.5 km/h)

Peak Torque: 305 Nm @ 2000 rpm
Con FIR: 327.6 Nm @ 2145 rpm
Senza FIR: 289.4 Nm @ 3180 rpm



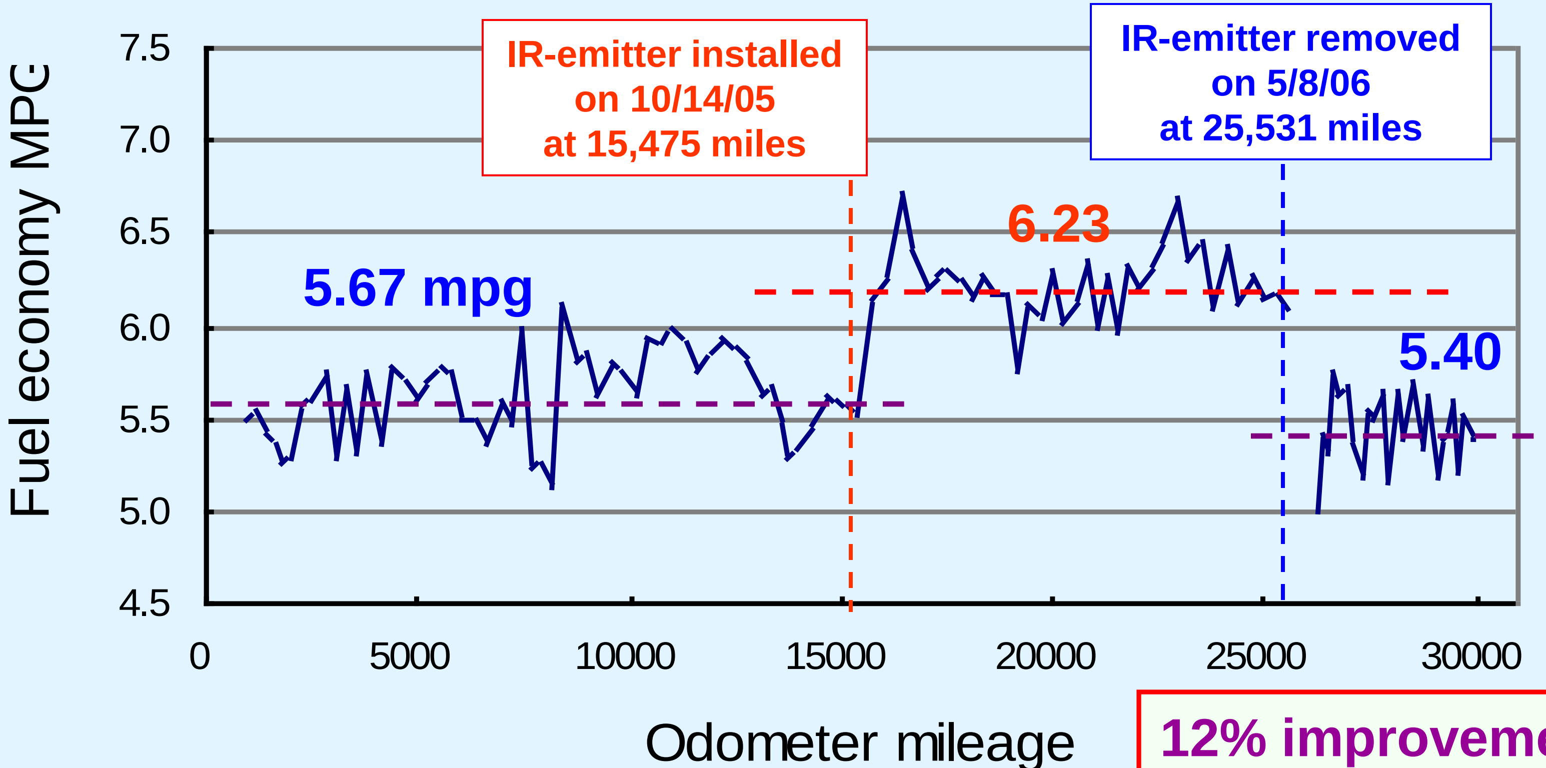


FIR helps increase power/torque at mid- and high-speeds.

School Bus Road Tests

2004 International School Bus CE

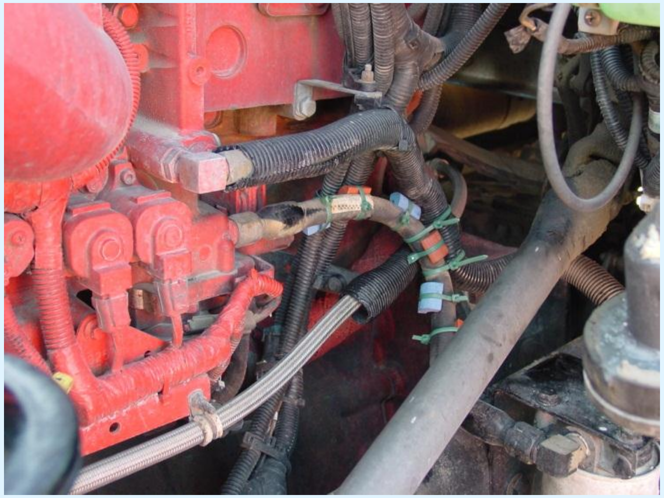
VT365 diesel engine V8, 6.0 L with EVRT



12% improvement in fuel economy

Diesel Trucks Fleet Test

2005 Kenworth T600A Tractor



Cummins ISX475
15 L 475 HP
HD diesel engine

3 sets IR-emitters installed

Test Tractor #:	2066*	2086	2246	2320	2325	2398	Total
5/12/07 Baseline MPG	6.62	6.26	6.81	6.65	7.63	6.37	
7/15/07 w/FIR MPG	6.68	6.51	7.31	7.36	7.84	6.69	
Total distance, miles	21,622	20,769	17,278	20,268	16,441	17,805	
Total fuels used, gal.	3,237	3,191	2,365	2,752	2,098	2,663	13,369
% MPG Improvement	0.9 %	4.0 %	7.3 %	10.7 %	2.7 %	4.9 %	5.9 %
Fuel Saved, gal.	ref.	129	173	294	57	131	784

6% improvement, or save 78 gallons per tractor per month

Summary & Conclusion

"using IR-excitation to improve fuel combustion efficiency of engines"

- **IR-emitters (3 – 14 μm) developed.**
- **Underlying science verified in methane-air counter-flow flame experiments:**
  - **IR-excited fuels burn faster, resulting in reduced fuel consumption rate and less CO & NO emissions**
- **Engine/vehicle test results demonstrate IR-effects on increasing engine efficiency**
- **More research to be done:**
  - **How IR-excitation participates in fuel combustion?**
  - **How IR-excited fuel improves engine performance?**