Ethanol Turbo Boost For Gasoline Engines

Diesel and Hybrid Equivalent Efficiency at an Affordable Cost

Excerpt from a presentation made on November 27, 2007 to the

National Research Council Committee

charged with the evaluation of

Fuel Economy of Light Duty Vehicles

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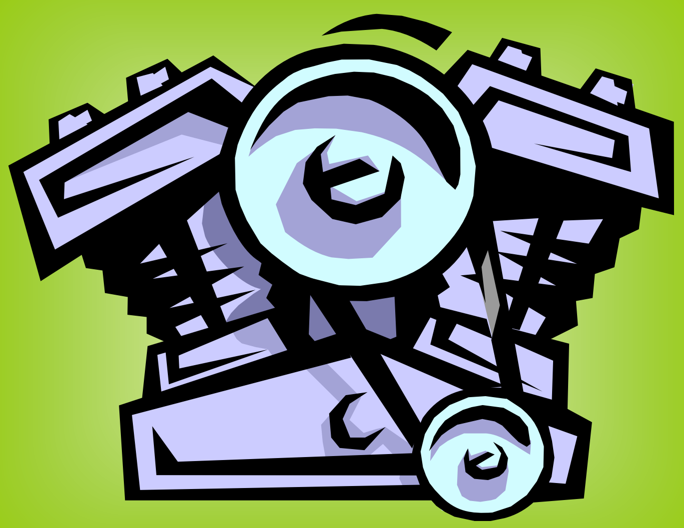
Objective:
Highest Efficiency Gasoline Engine

Replacement of a standard gasoline engine…



… with a much smaller, turbocharged engine with same or greater power

DI Ethanol

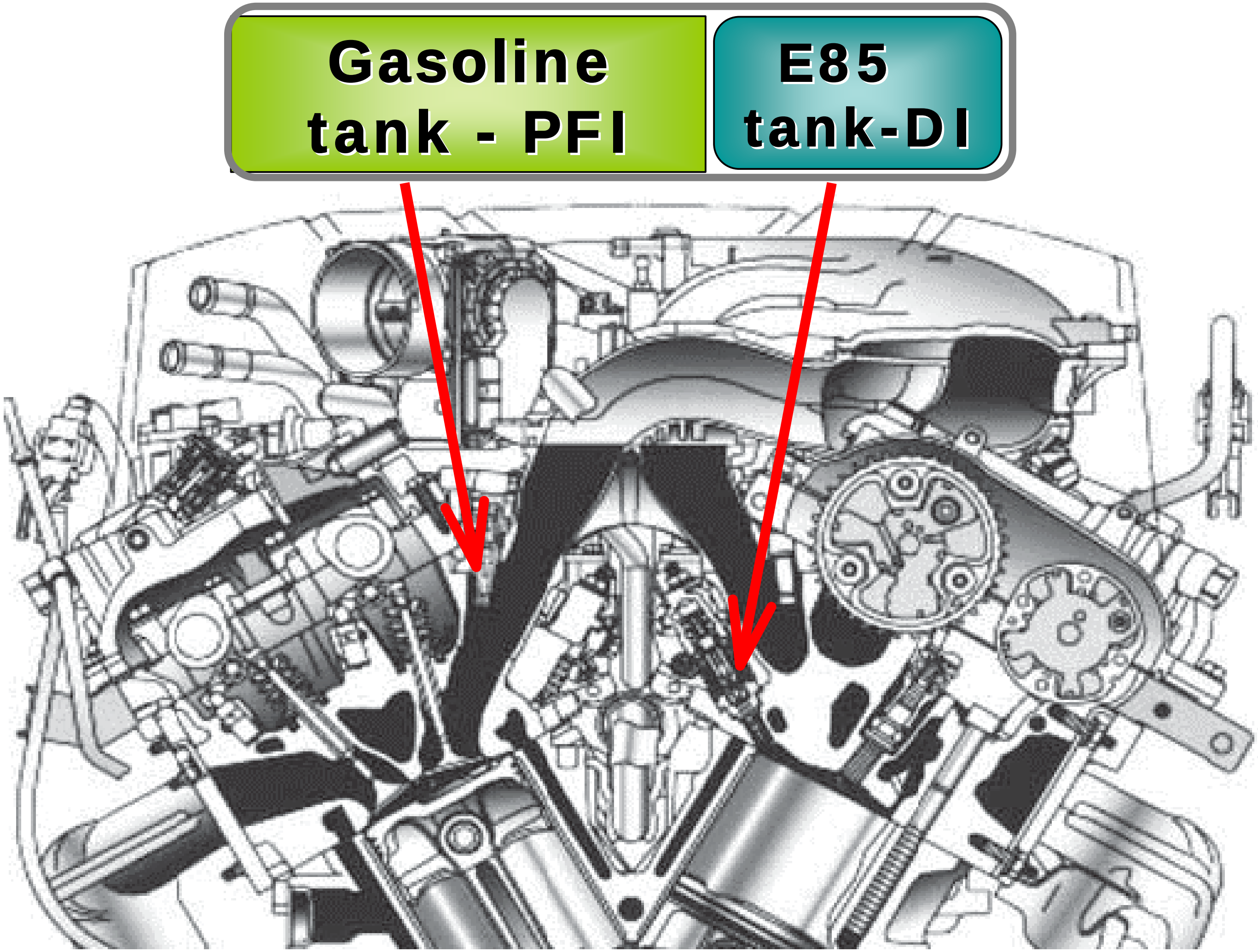
+

Highly turbocharged, high compression ratio

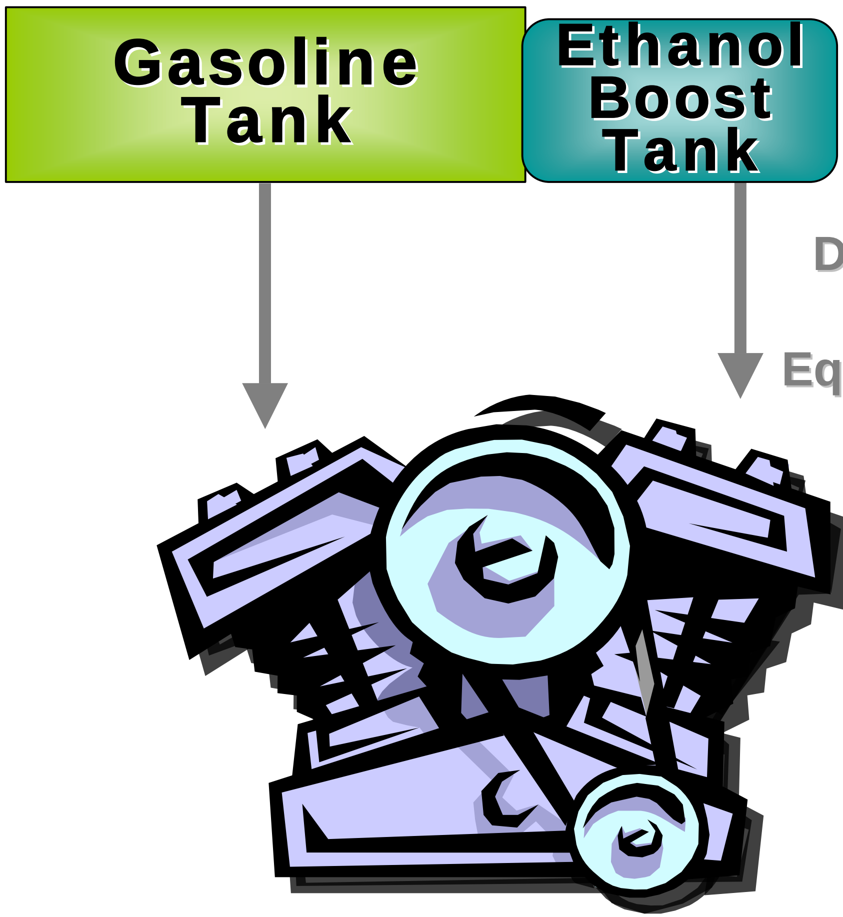
DI Ethanol (E85) Injection Removes Knock Limit on Engine Performance

- Directly injected ethanol essentially removes knock limit by large evaporative cooling effect
- Allows highly turbocharged, high compression ratio operation: highly downsized, high torque/power density, high efficiency engines
- Ethanol provided by second tank or fuel compartment (can be in form of E85)
- Ethanol consumption is controlled to a minimum by using only at higher levels of torque where knock would otherwise occur – i.e., “octane on-demand”
- More efficient and lower cost than Variable Compression Ratio (if it could be developed) since high compression ratio can be maintained at high torque

DI E85 and Gasoline PFI in the Same Engine



Highest Efficiency Gasoline Engine
"Octane On-Demand" Boost
Using
Direct Injection of Ethanol



Direct Injection suppresses knock at high torque
Equivalent to >150 octane fuel

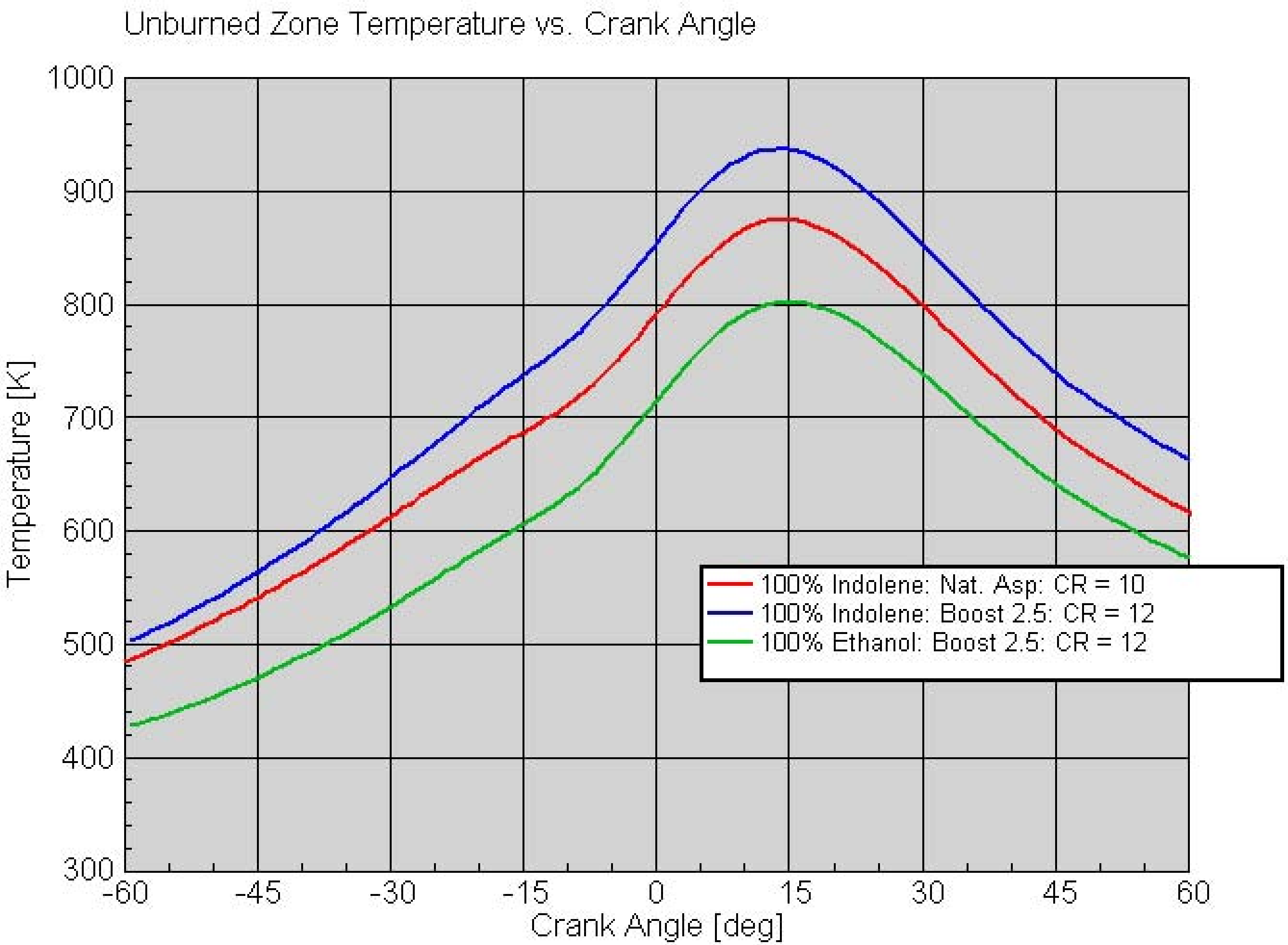
Highly turbocharged, downsized, high compression ratio engine

Fuel Properties and Characteristics

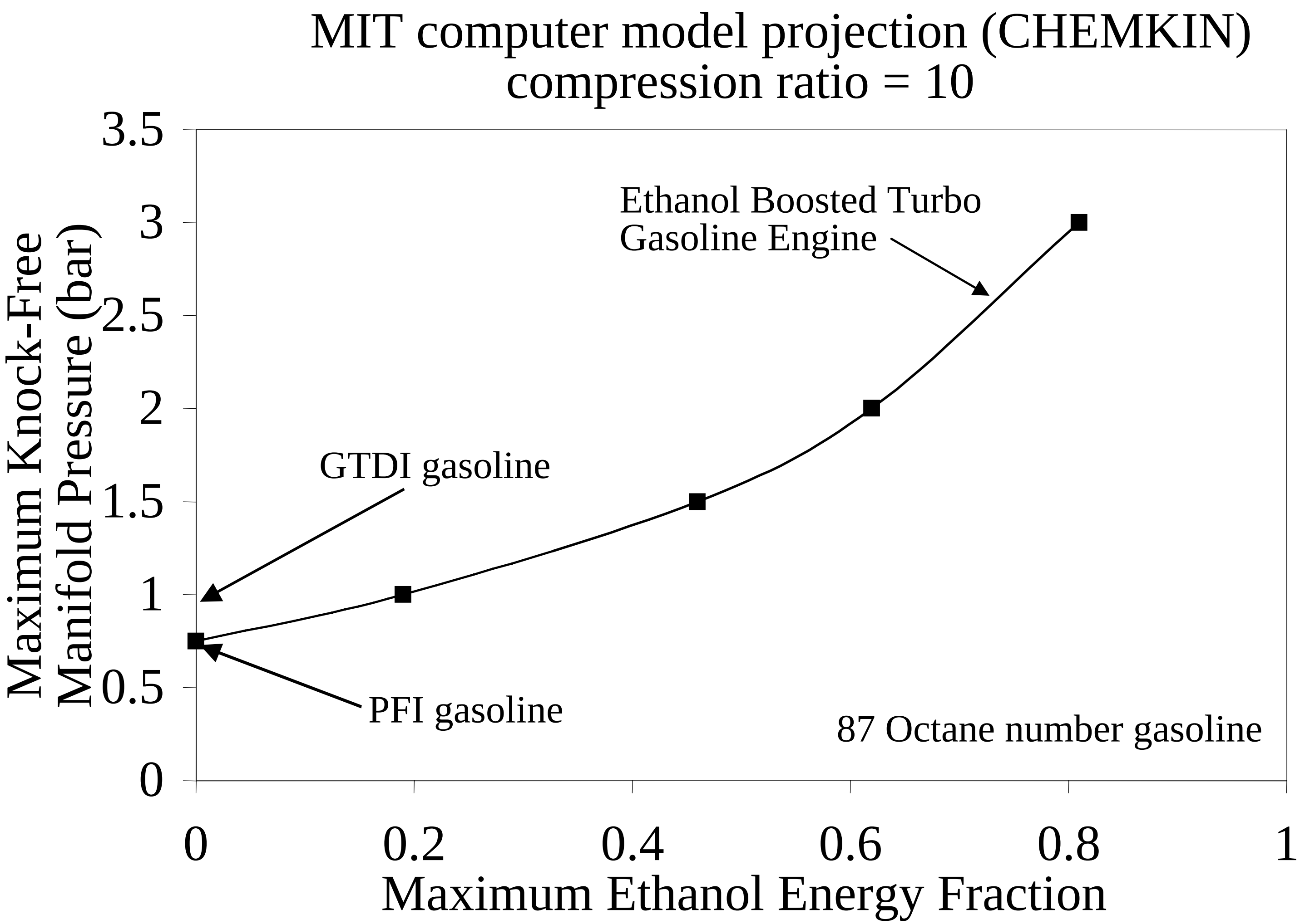
	Gasoline	Ethanol	Methanol
"Chemical" Octane (RON)	91 - 98	107	106
Stoichiometric A/F	~14.6	9.00	6.47
Heat of Vaporization @ 298 K (kJ/kg)	~350	924	1177
Heat of Vaporization of Stoichiometric Quantity of Fuel	base	4.28 x base	7.59 x base
Lower Heating Value (MJ/kg)	~44.0	26.8	21.1
Heating Value of Stoichiometric Quantity of Fuel	base	0.99 x base	1.08 x base
Density (kg/liter)	~0.75	0.785	0.792
Heating Value – Volumetric Basis (MJ/liter)	base	0.64 x base	0.51 x base

“End Gas” Temperature

DI Ethanol Evaporative Cooling Effect



DI Ethanol-Enabled Increase in Knock-Free Manifold Pressure and Torque



Engine Features

- **Stoichiometric fuel/air ratio**

  - Use of 3 way catalyst
  - Higher torque for a given size engine than diesel

- **Illustrative features**

  - Compression ratio of 12 -14
  - Manifold pressure increased by a factor of 2.0 to 2.5 X ambient pressure by turbocharging
  - Engine downsized by a factor of 0.4 – 0.5 relative to PFI engine
  - Diesel-like structure
  - Can employ VCT or EGR for further efficiency increase under throttled conditions

Turbo-Diesel Equivalent Efficiency with Lower Emissions and at Lower Cost

Baseline Naturally aspirated PFI at comparable torque	Gasoline Turbo Direct Injection (GTDI)	**Ethanol Boost Turbo Gasoline**	Clean Turbo Diesel
Efficiency gain ✫ relative to gasoline PFI	10 - 15% (15% - premium gas)	25 - 30% (regular gas)	25 - 30%
Vehicle air pollutant emissions	Very low (can be lower than diesel)	Very low (can be lower than diesel)	Needs advanced exhaust treatment
Power relative to gasoline PFI	~ same	~ same or greater	~30% less
Extra fluid additive	——	Ethanol/E85	Urea
Additional cost rel to gasoline PFI	~$1,000	~$1,400	~$5000

✫ **Efficiency in miles/BTU or gm/mile CO_2**

Comparison to Full Hybrid (HEV)

	Gasoline/Electric Hybrid	Ethanol Boost
Efficiency Gain	25 - 35%	30– 35%*
Extra Cost	$3,000 – $5,000 ➢$5,000 for larger gasoline engine vehicles + possible battery replacement cost	$1,000-$1,500
Technology	•Gasoline engine •Electric motor •Batteries •Adds weight	•Turbocharged gasoline engine •Ethanol direct injection •Reduces weight

***A simple engine "stop-start" system can be added to the small EBS engine for additional efficiency in city driving, bringing the total gain to 30-35%**

Relation to Gasoline Turbo DI (GTDI)

- Natural extension of GTDI
- Adds port fuel injectors and second tank or separate fuel compartment within single tank
- Increases compression ratio and boost capability
- Requires strengthened engine structure, e.g., CGI block.
- Can double efficiency gain of GDTI for an incremental \$300 - \$400, .i.e., 25% - 30% improvement for EBS with regular, unleaded gasoline vs. 12% -15% for GTDI.

Ethanol (E85) Requirements

- Special fuel management system provides capability to limit required ethanol consumption to a small fraction of gasoline consumption over a drive cycle
  - Initial system (PFI regular gasoline, DI E85): 5% or less
  - Advanced system: 2.5% or less

- Illustrative ethanol (E85) consumption (4% E85 use)
  - 10 gallons/5000 miles for large pick up truck
  - 5 gallons/5000 miles for sub-compact car

Ethanol Boost Tank Refill Options

- Refuel using expanding availability of E85 pumps (could also use E85 in primary tank and operate as flex fuel vehicle)

- Refill with ethanol (E85) every 4 to 6 months at dealer, garage (similar to proposed urea refill for diesel SCR)

- Service station attendant or driver refills using containers

- In worst case of no ethanol/E85, vehicle would still be highly drivable with approximately 50% torque (use would not be prohibited by EPA as in case of “outage” of urea-SCR for diesel)

Enhancing The Value of Ethanol

- Leveraged impact on gasoline powered engine performance and efficiency - increases value of ethanol; attractive even at high price

- Allows impact of available ethanol to be applied over a much broader number of vehicles

- Increased energy security and environmental benefits obtained with only a limited amount of ethanol (reduced NMOG emissions with gasoline cold start)

- EBS technology also enables highest efficiency flex fuel vehicle
  - E85, gasoline-E85 mixtures or gasoline used as fuel in primary tank
  - 25 – 30% higher efficiency than conventional flex fuel vehicle

Illustrative Applications

- Large engines for SUVs, light-medium duty trucks (*e.g.* > 5 liter)
  1. Replace diesel engines with lower cost, cleaner and more powerful gasoline engines
  2. Replace present gasoline engines with much smaller engines that provide at least 25% greater efficiency and 25% more torque

- Small engines for cars (*e.g.* 2 liter or less)
  1. Replace present gasoline engines with much smaller engines that can provide very high mpg plus higher torque

     (*e.g.* increase mpg from 36 mpg to 45 mpg)
  2. Provide much greater power/torque

     (*e.g.* 330 hp, 360 ft-lbs peak torque from 1.9 liter engine)

EBS Technology:
A Major New Option For Higher Fuel Efficiency

- Affordability (low upfront cost and short payback time) is key to mass market penetration of high efficiency vehicles with desirable consumer attributes and, therefore, to a significant impact in reducing petroleum consumption.

- EBS technology provides an *affordable option*. It delivers –
  - Comparable fuel efficiency to hybrid and clean diesel at much lower cost (approximately one third)
  - Near term – *no inventions required,* only product intent and normal product development)
  - Lower emissions and more robust to future environmental regulations than diesel
  - More robust to climate variation and long-term durability than hybrid
  - Reduced weight (especially relative to hybrid)
  - Higher value use of ethanol and an increase in its economic attractiveness
  - High efficiency flex fuel vehicles with 30% improved MPG on E85

EBS Commercialization Plan

- Collaborative R & D with Ford :

  -- Early engine measurements at Ford have confirmed large increases in knock-free torque consistent with predictions of MIT computer model

  -- Subcontractor to Ford on major DOE Cooperative Agreement for demonstration of technology
- Collaborative R&D with Mack Truck/Volvo AB for certain heavy duty applications (currently diesel)
- Establishment of relationships with other auto and truck manufacturers
- Prototypes and further technical innovations and improvements to EBS technology
- EBS production vehicle target: 2012