Improving the Fuel Economy of Heavy Duty Fleets II
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Heavy Duty Truck Fuel Economy Options

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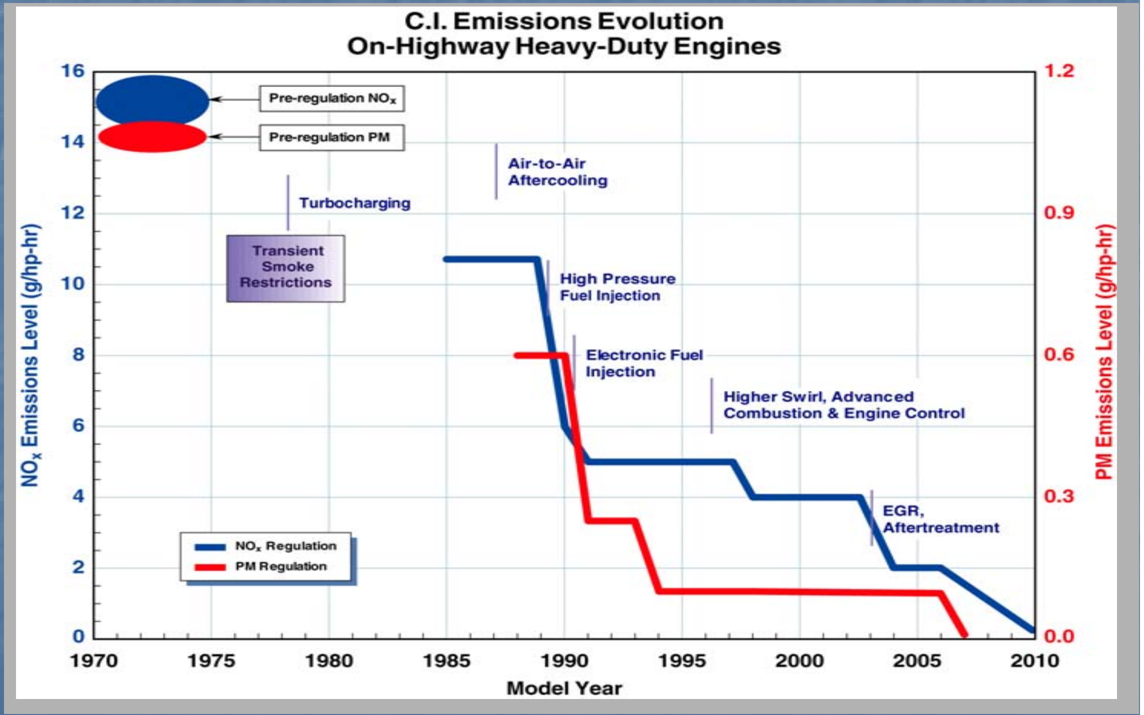
Outline

- Background/history
- Current project objectives
- Project approach
- Technology examples
- Technology packages
- Summary

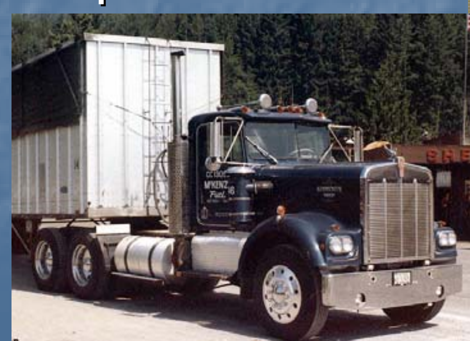
Background/History

- Diesel engine efficiency gradually improved from the early 1900s to the 1970s, when emissions became a focus of engine development
- Early emissions reductions came with efficiency improvements
- Latest emissions reductions resulting in efficiency losses



Background/History

- Non-vertically integrated HD truck industry
  - Vehicle advances delayed somewhat from engine development
- Vehicle development traditionally directed towards comfort/convenience more than fuel economy
- Fleet vs. owner/operator trends
  - Fleets lead fuel economy developments in trucks
- Vehicle technology for improved fuel economy is available but not highly desired in the market
  - Fuel prices have large impact on desire



Current Project Objectives

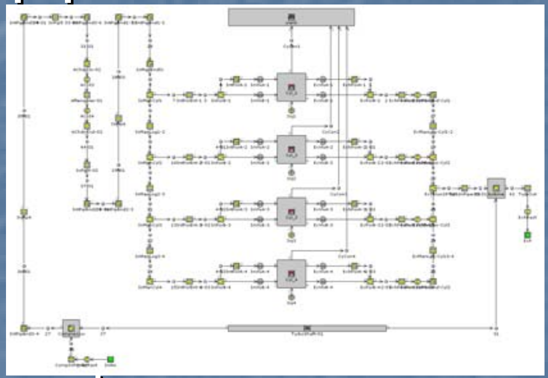
- With the near-term 2010 emissions objectives within reach, what can be done to improve HD truck fuel economy while maintaining extremely low tailpipe emissions?
- Determine the most feasible and cost-effective technologies for improvement of real-world fuel economy on the over-the-road HD truck fleet
- Quantify the potential magnitude of improvement that can be obtained with respect to initial cost and other market drivers

Project Approach

- Select a baseline HD truck/engine combination to serve as reference
  - Kenworth T600
  - Volvo D13
  - 10 speed transmission
- Consider and select a number of potential fuel economy improving technologies for both engine and vehicle
- Build these technologies into a limited number of technology packages for evaluation
- Build engine and vehicle computer models of the baseline
- Analyze the technology packages with the models

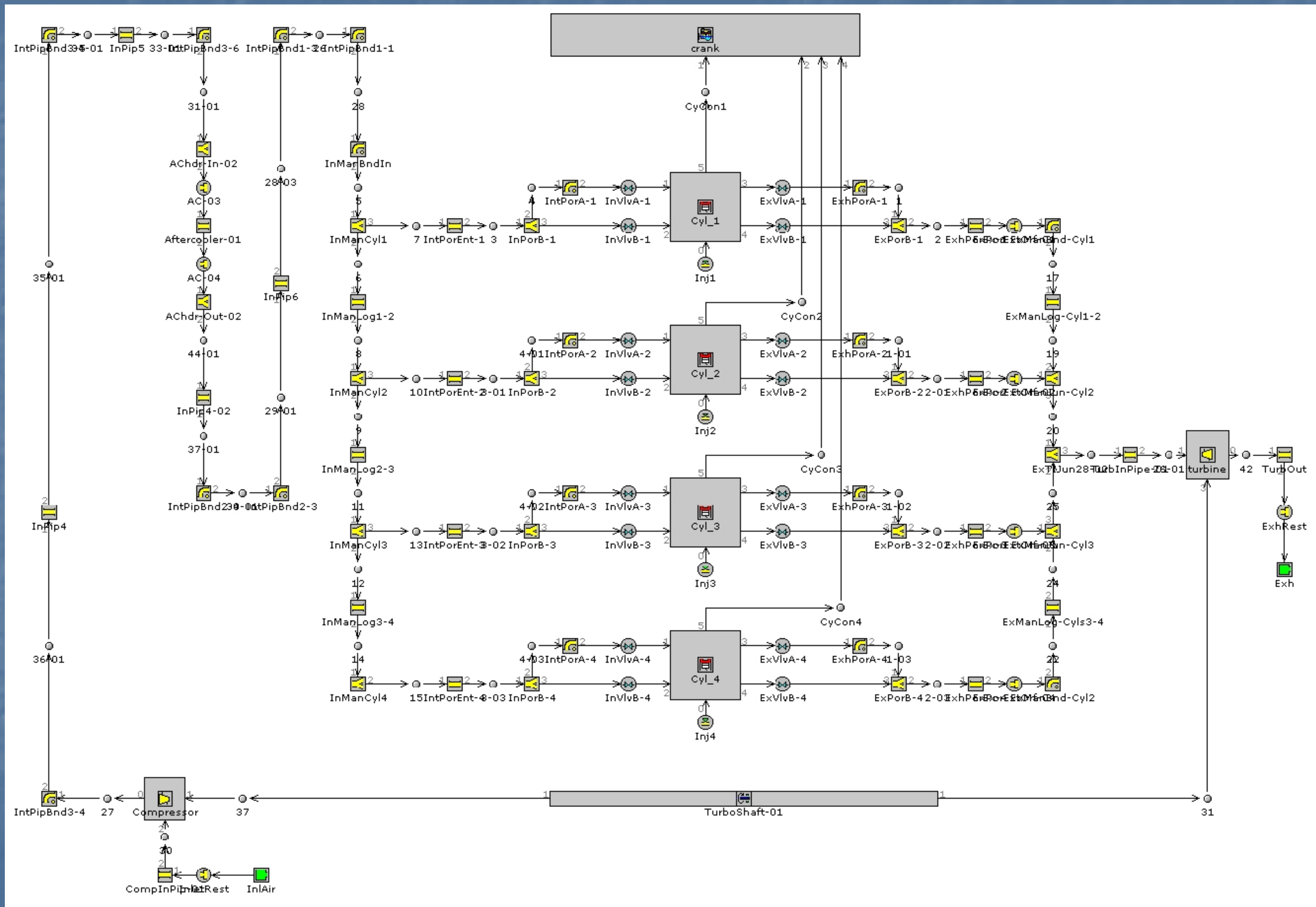
Project Approach - Models

- GT-Power will be used for engine modeling
  - 1-D cycle simulation code
  - Calculates every pressure, temperature and mass flow rate through the system at every time step, typically ¼ to ½ crank degree
  - Includes everything from air filter to tailpipe
    - Manifolding
    - Turbomachinery
    - Valve events
    - EGR loops
    - Aftercooler
    - Heat release (combustion) and in-cylinder heat loss



  - Will be used to generate fuel consumption maps for the engine with various engine technology packages applied

Project Approach - Models



Project Approach - Models

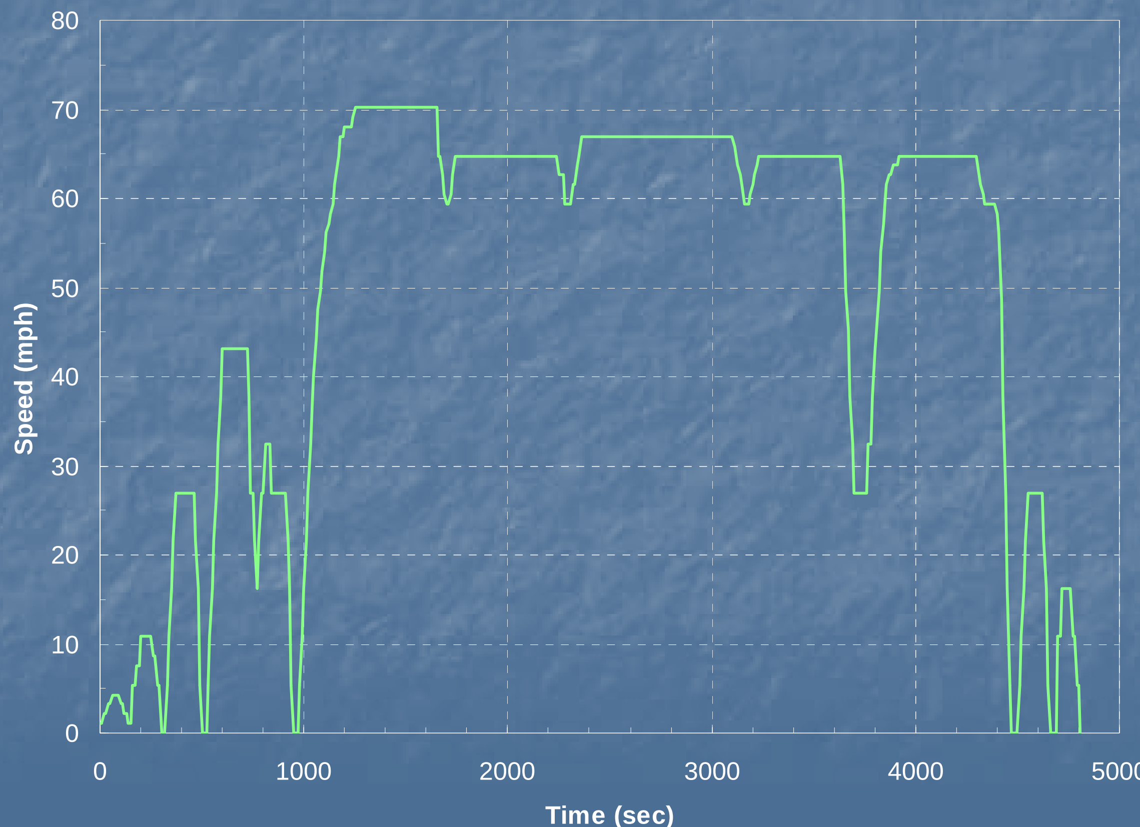
- The engine model provides the most accurate results when baselined to the closest available engine data
- SwRI is conducting a HD engine benchmarking program from which we are able to utilize results for baseline calibration of the engine model to a 2007MY configuration
- After baseline matching, the model will be adjusted to provide expected 2012 emissions solution and relevant engine performance characteristics
- Of the appropriate engines, this data is first available for the Volvo D13 so that is the engine that will be modeled and used for the study
  - This engine not actually available in the selected truck commercially, but representative of the general class of engines that are available
- This closely-related baseline of very new data provides the best accuracy of the model predicting forward

Project Approach - Models

- Raptor® will be used for vehicle modeling
  - Simulates any definable drive cycle
  - Uses engine performance maps (derived from GT-Power), and takes into account
    - Rolling resistance
    - Aerodynamic drag
    - Grade
    - Powertrain losses
    - Hybridization
  - Produces predictions for vehicle fuel consumption and emissions over defined drive cycle

Project Approach – Drive Cycle

- Drive cycle selection is critical parameter in driving best real-world improvements
- Modification of CA HDD Highway Line Haul Drive Cycle
- Increased speed by 8%
- Additional segments at high speed



Technology Examples
(with fuel consumption reduction estimates)

- Engine technologies
  - Engine friction reduction (1%)
  - Controls refinements (1%)
  - Improved air handling
    - Turbocompound (-1 to +4%)
    - 2-stage with intercooling (0 to 2%)
    - High efficiency turbocharging (0 to 2%)
    - EGR pump (0 to 2%)
    - Variable valve actuation (1 to 4%)
  - Alt. combustion strategies (0 to 2%)
    - HCCI/PCCI
    - LTC
  - Thermal management
    - Insulated ports/manifolds (0 to 1%)
    - Bottoming cycle (10-40%)

Technology Examples
(with fuel consumption reduction estimates)

- Vehicle technologies
  - Drivetrain
    - CVT (0%)
    - Automated manual (4 to 5%)
    - Hybridization (3 to 15%)
  - Accessory electrification (1 to 2% per accessory)
  - Efficiency
    - Lubricants, parasitic drag (up to 2%)
  - Aerodynamic drag (up to 5%)
  - Mass reduction (up to 4%)
  - Rolling resistance (2 to 3%)
  - Other
    - Routing, increased GVW, etc. (up to 10%)

Technology Ranking

- In order to reach a manageable number of combinations to model, technologies were ranked
- Full group discussion with input from steering committee
- Considerations
  - Potential fuel economy gains (estimated)
    - Fuel economy gains obtainable in key operating areas
  - Initial cost
  - Packaging
  - Adverse effects on drivability, ability to complete mission
  - Avoid including very similar technologies to allow inclusion of wider variety of approaches

Technology Packages

- After the individual technologies are selected, they are grouped into technology packages
- Scope of project allows ~8 packages to be modeled and quantified
- Look for synergies between engine and vehicle technologies
- Try to provide a few different, internally consistent packages
  - Lower initial cost, more conservative effort on both engine and vehicle side
  - Higher initial cost, more aggressive effort on both engine and vehicle side
  - Infrastructure considerations

Technology Packages

- Example package (moderate) to show synergies and other considerations
- Vehicle improvements
  - Moderate aero package
  - Reduced rolling resistance (super single tires)
  - Reduced drag (lubricants, brakes, bearings)
  - Electrified accessories (limited to 24VDC-capable items)
- Engine Improvements
  - Turbocompound
  - Exhaust port liners
  - High efficiency turbo

Technology Packages

- Synergies/rationale for moderate package selection
  - Turbocompound with high efficiency turbo provides maximum turbocharger performance and power reclamation while still providing negative delta P required for EGR flow
  - Exhaust port liners maximize heat to turbines that can now be captured via turbocompound
  - Turbocompound could be electric and provide energy to drive accessories
  - All pieces of package are available technology that have been applied in limited fashion to production engines/vehicles
    - Common risk/initial cost level across engine and vehicle
    - Other packages are higher or lower risk, but attempt to be consistent risk level within a given package

Technology Packages

- Final package will be "best of"
  - Will include learning from evaluation of other packages and intended to be a very aggressive grouping of technologies that provide a large magnitude benefit
  - Likely technologies:
    - Variable valve timing
    - Bottoming cycle
    - Exhaust port liners
    - Electrified accessories
    - Full aero package
    - Low rolling resistance
    - …
  - Objective is to determine best achievable performance

Status

- Initial engine data from benchmarking program available mid-February for D13
- Engine and vehicle model construction in process
- Cost estimating in process
- Maintain communication with industry and steering committee throughout to insure that the correct effects and magnitudes are captured

Next Steps

- Baseline engine model against 2007MY data
- Adjust to 2012MY performance for project baseline
- Apply technology packages and generate fuel consumption, emissions maps
- Use maps in vehicle model, with vehicle improvements applied, to generate fuel consumptions and emissions results over the driving cycle
- Make conclusions re: most effective fuel consumption and emissions reductions strategies and quantify the benefits for a 2017 approach

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