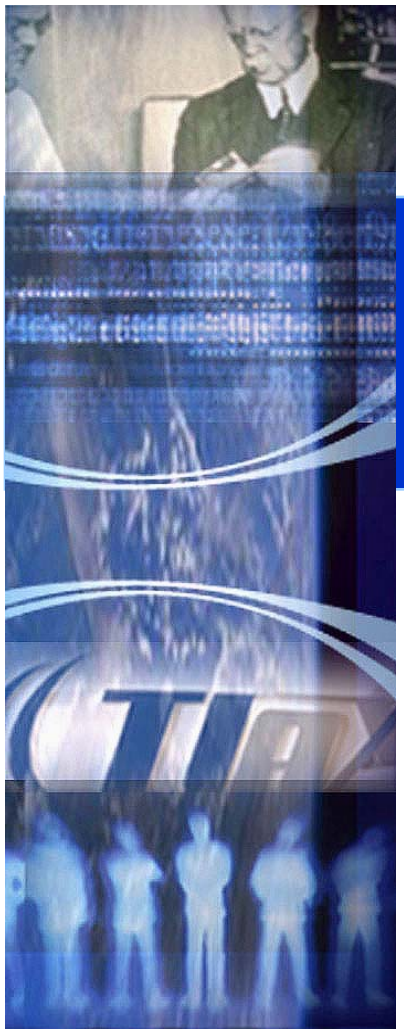

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Heavy Duty Truck Fuel Economy Options- Cost Effectiveness and Fuel Economy Impact

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2. Costing Approaches
3. Fuel-saving Technologies- three examples
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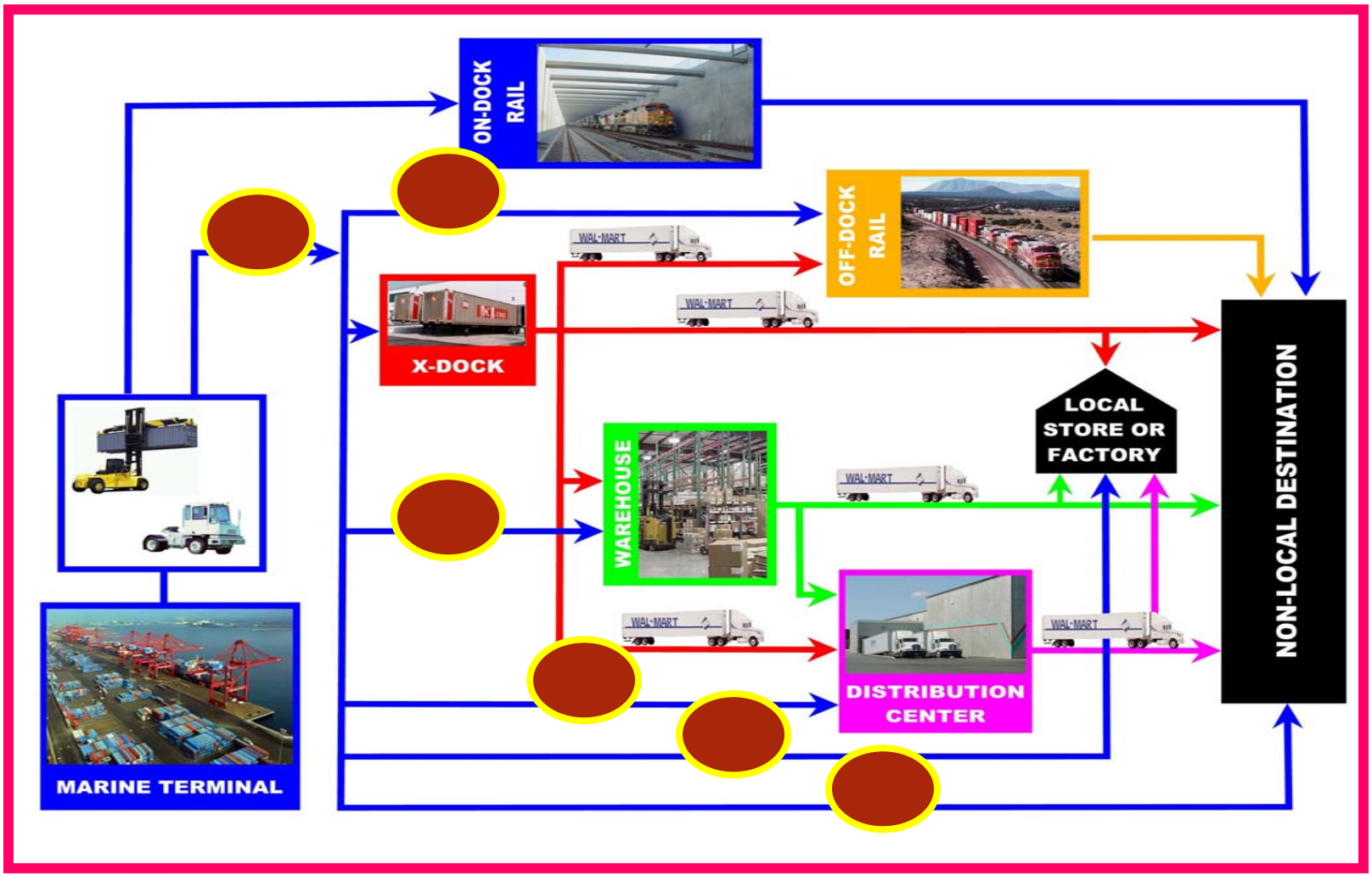
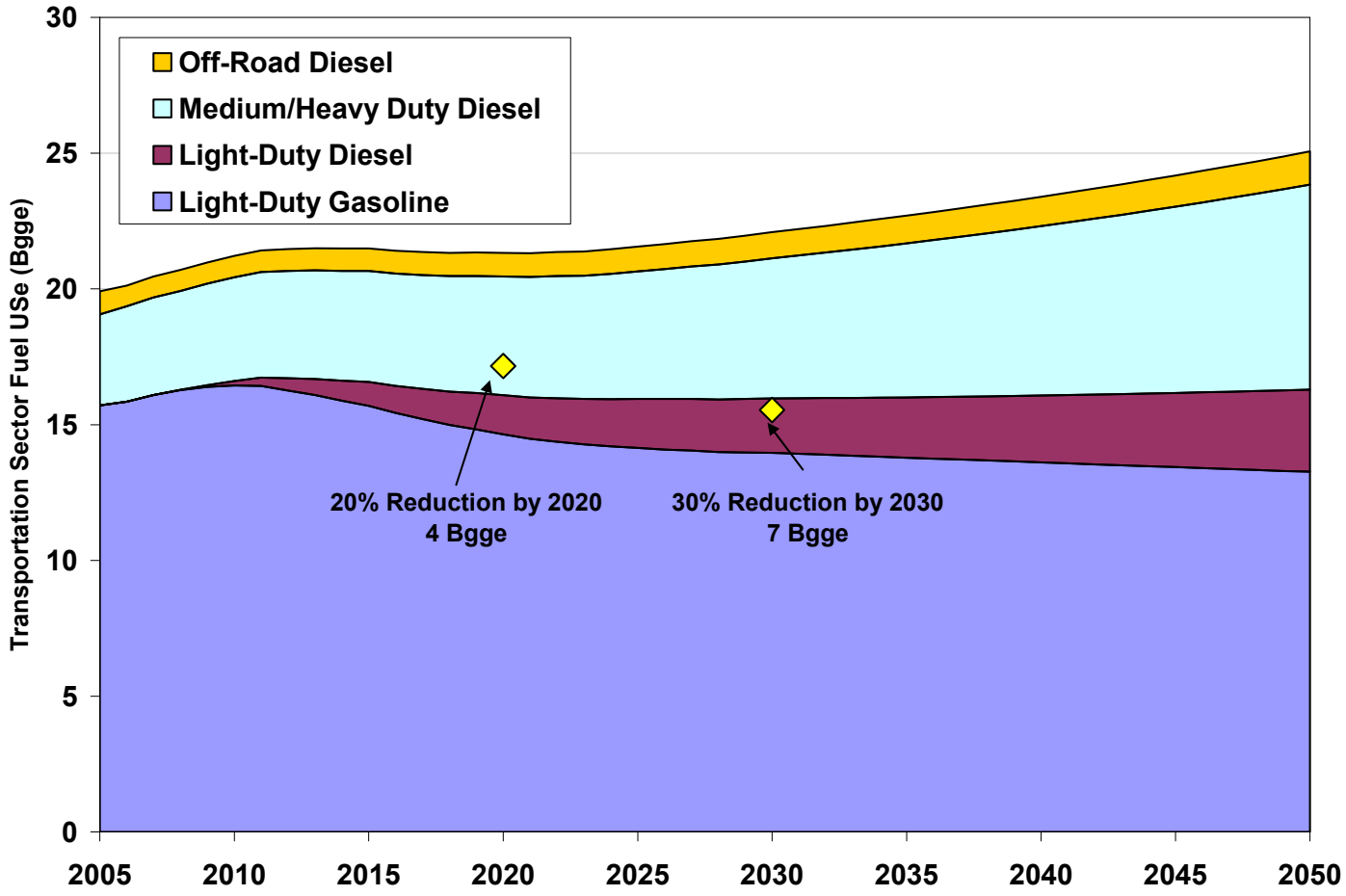
Heavy-duty on-road trucks are ubiquitous in the logistics chain for goods movement in most of America. Class 8 trucks account for 11-12% of all US petroleum



Heavy Duty Trucks represent a demand for diesel fuel that is expected to grow at 4-5%/yr; proven technology is available for raising fuel economy



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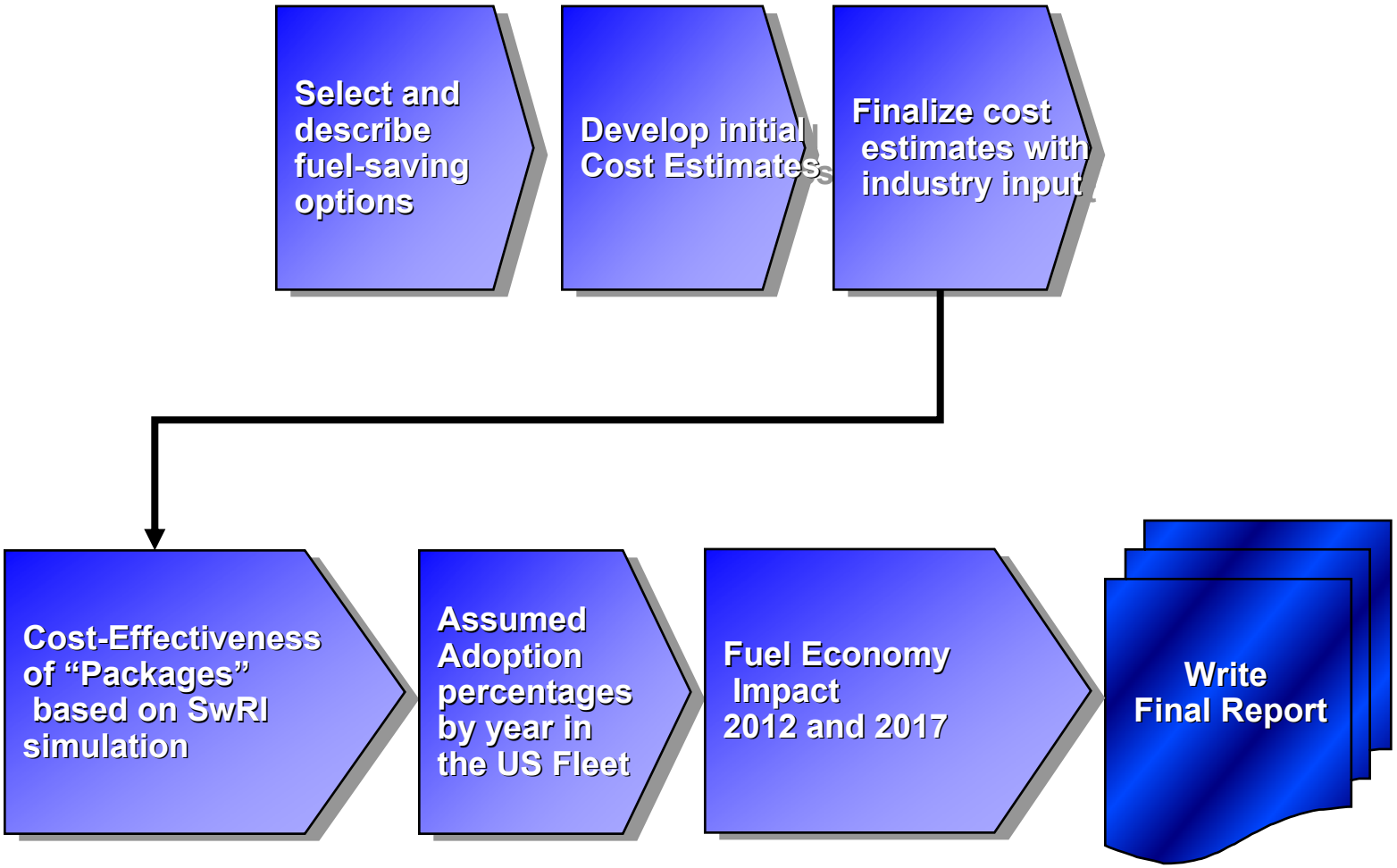
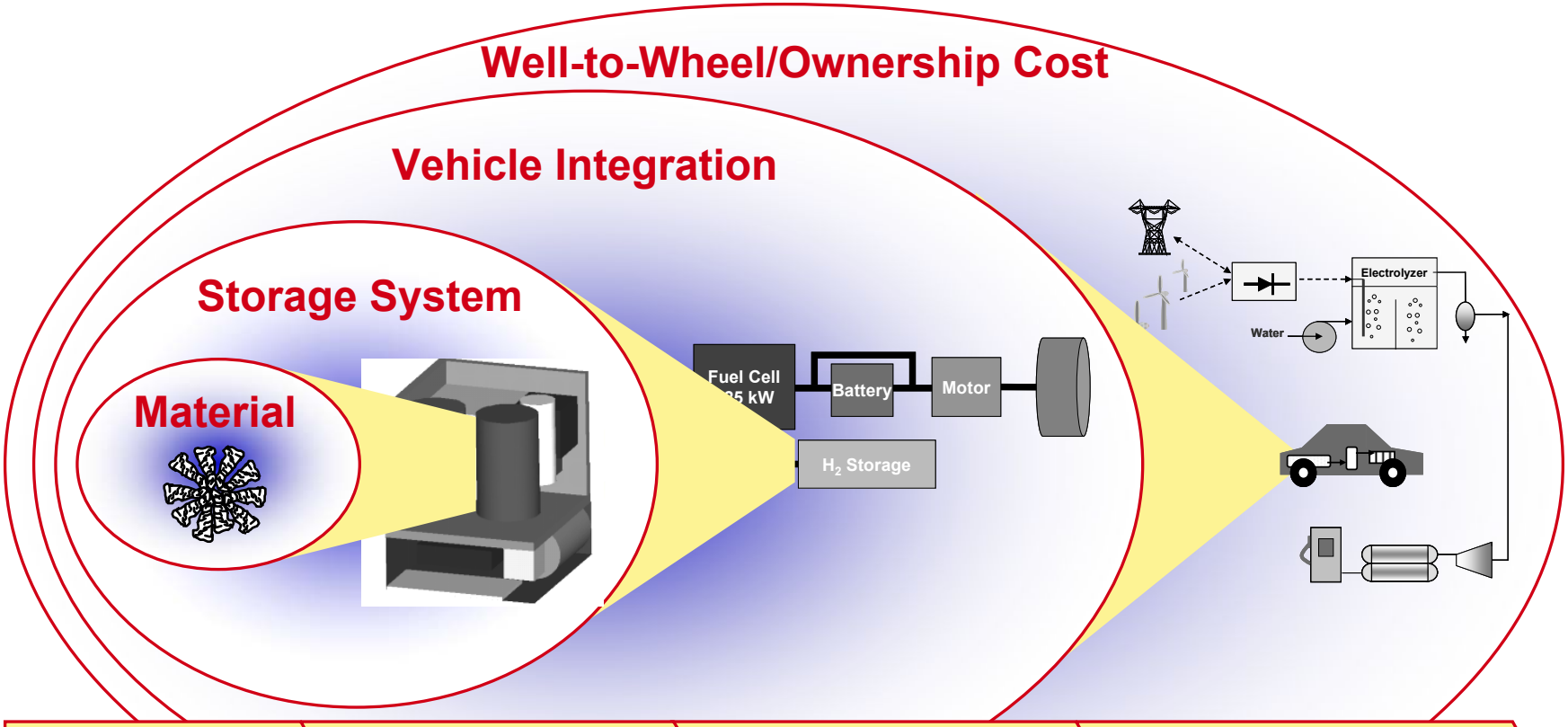
Steps in the Approach



TIAX has performed numerous Well-to-Wheel and Ownership Cost assessments for advanced automotive technologies.



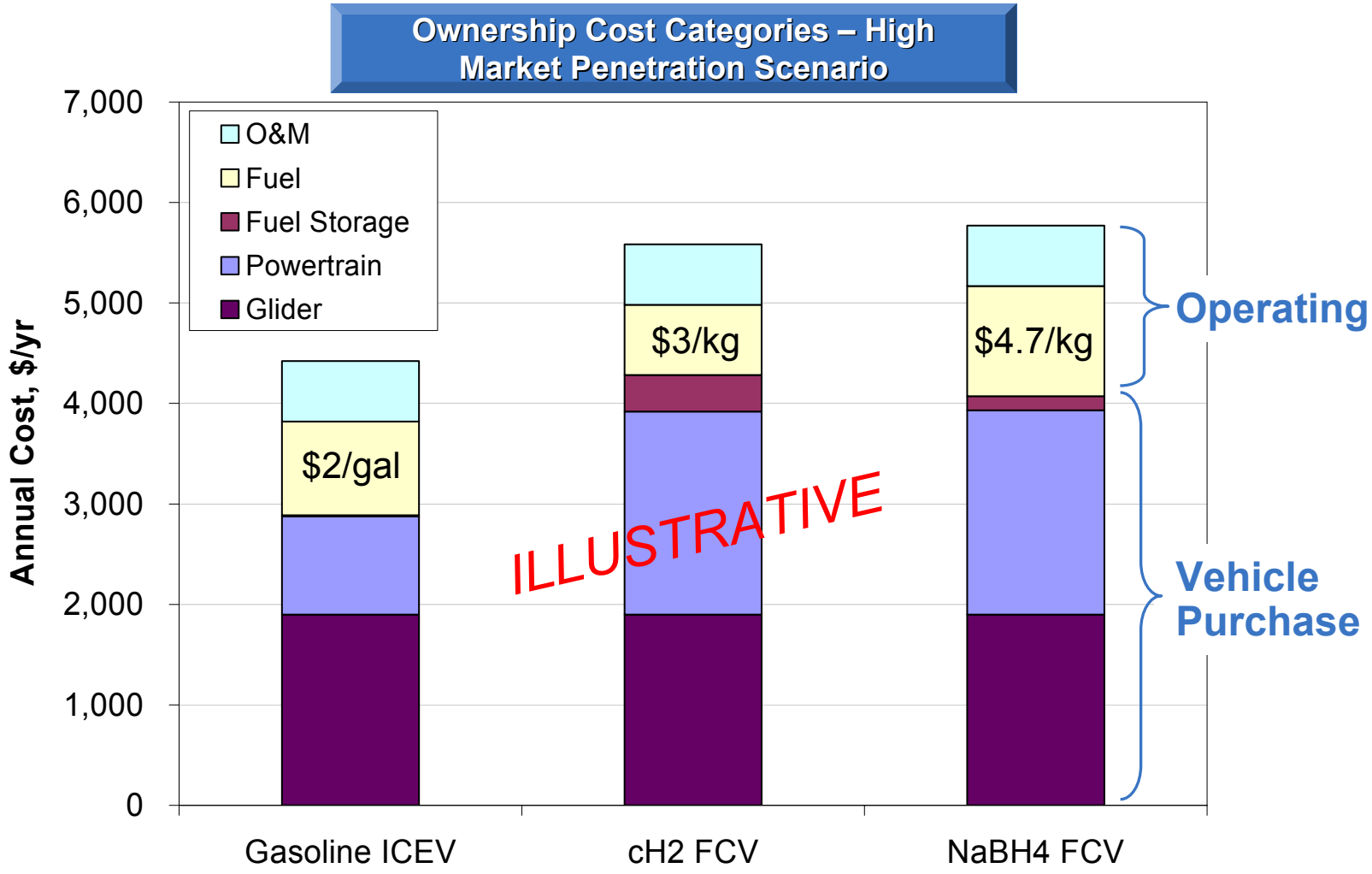
- Material wt %
- P, T requirement
- Thermo, kinetics

- BOP requirements
- System size, cost
- System issues

- Power unit and thermal integration
- Vehicle cost, weight
- Fuel economy

- Fuel chain requirement
- Ownership cost
- WTW energy use, GHG

A complete ownership cost assessment requires that both vehicle purchase cost and operating costs be considered.



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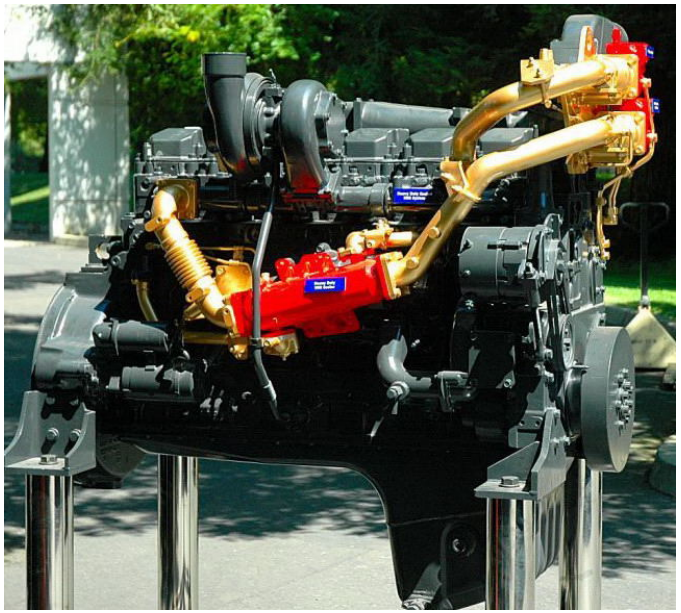
Cost of Fuel Saving Technologies are based on implementation on a baseline truck meeting 2010 emission standards



Baseline Truck: Kenworth T-600
Engine: Volvo 13 liter D13 In-line 6-cylinder
10-sp manual transmission
Cummins Emissions Solutions exhaust treatment
Price $125,000- 135,000 fleet purchase basis

Three Fuel-Saving Technologies at various stages of development

Commercialization Stage Gates for New Fuel–Engine Technologies

Timeframe							
TRL* Stages 1-2	**Stage 3**	**Stage 4**	**Stage 5**	**Stage 6**	**Stage 7**	**Stage 8**	**Stage 9**
Academic Research	Proof of Concept Research of Components at Bench Scale (flow-reactor tests, modeling)	Proof of Concept Lab Validation lintegrating the Components (successfully test ad-hoc hardware on engine dyno)	Breadboard Validation in Realistic Environment (“acts like” hardware in Test Vehicle)	Prototype Demonstration (Looks-like hardware in Test Vehicles)	Fleet Demonstration for Intended Major Customer (Pre-production cost unit)	First Commercial Fleet (extended operation and publicity)	Commercial-ization and Replication
			Note: Minimum time from lab validation to commercial replication (stage 4 to stage 9) is typically 5-7 years.				

Exhaust Heat Recovery (Bottoming Cycle)

Hybrid Electric Drive-train

Aerodynamics, low mass wheels, low rolling-resistance tires, electrification of certain auxiliaries

Cost Example- Available Technology: "Vehicle Upgrade Package"

- Moderate Aerodynamics package
- Low mass wheels and low rolling resistance tires (i.e. super singles)
- Reduced drag
- Electrification of Auxiliaries (water pump, oil pump, power steering)

Preliminary Price $8000- 10,000 incremental cost; fleet purchase

Basis of estimate- Trailer streamlining, low mass wheels and low rolling resistance tires price based on SmartWay program estimates. Auxiliary electrification estimated through literature search. Manufacturers asked to confirm these estimates as well as provide help on reduced brake and wheel bearing drag & low viscosity lubricants advancements.

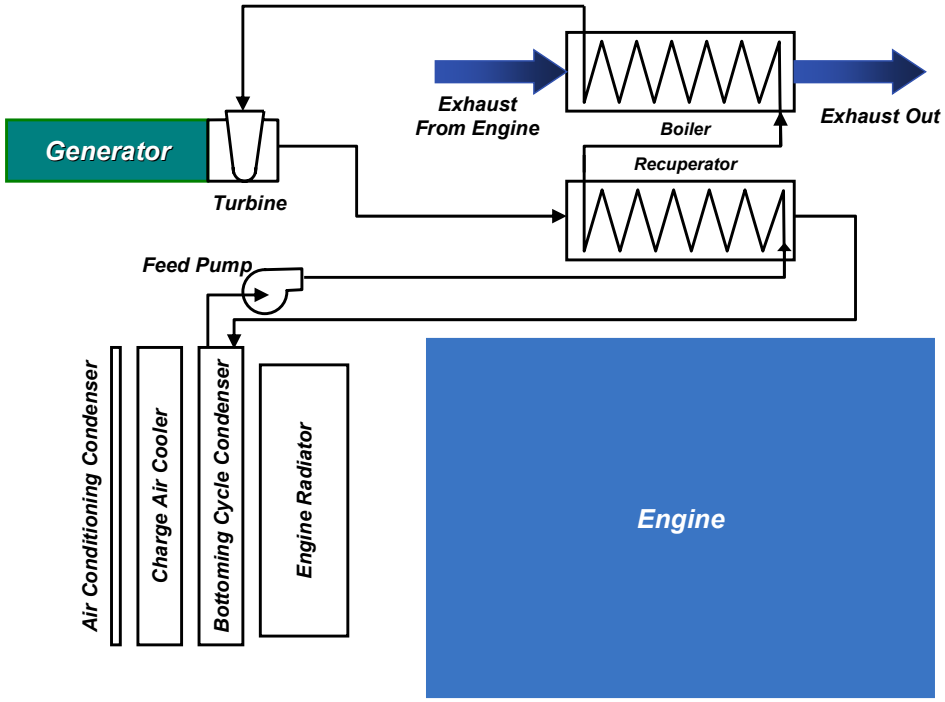
Cost Example- Emerging Technology: "Hybrid-Electric Truck Package"

- Integrated Starter-Generator
- Automated Manual Transmission
- Advanced battery pack capable of supporting hotel loads for 55mins/hour
- Electric Heating and Air Conditioning

Preliminary Price $20,000- 30,000 incremental cost; fleet purchase
Basis of estimate- Cost estimate for HEV package comes for an estimated payback period of three years or less using between 7%-9% fuel economy improvement. The hybrid package is expected to be added to the Vehicle Upgrade Package.

Cost Example- Future Technology: "Bottoming Cycle Package"

- Early-stage designs are currently being explored by selected engine manufacturers (DEER Conference). It is not clear whether bottoming cycles will be feasible and practical for potential widespread adoption by the trucking industry by 2017.
- Issues include cost, packaging, weight, maintenance/reliability and controls
- Sweet spot for bottoming cycle will be highway cruise at 120 kW; estimates suggest about 12 kW power is recoverable
- System consists of four modules: (1) steam boiler supplied by the recoverable heat from the 300 C exhaust, (2) high speed turbine expander – generator, (3) condenser : finned-tube air cooled heat exchanger, (4) recuperator



Preliminary Estimate:

$15,000- 20,000 incremental cost

Basis of estimate- add cost of four modules plus system integration cost

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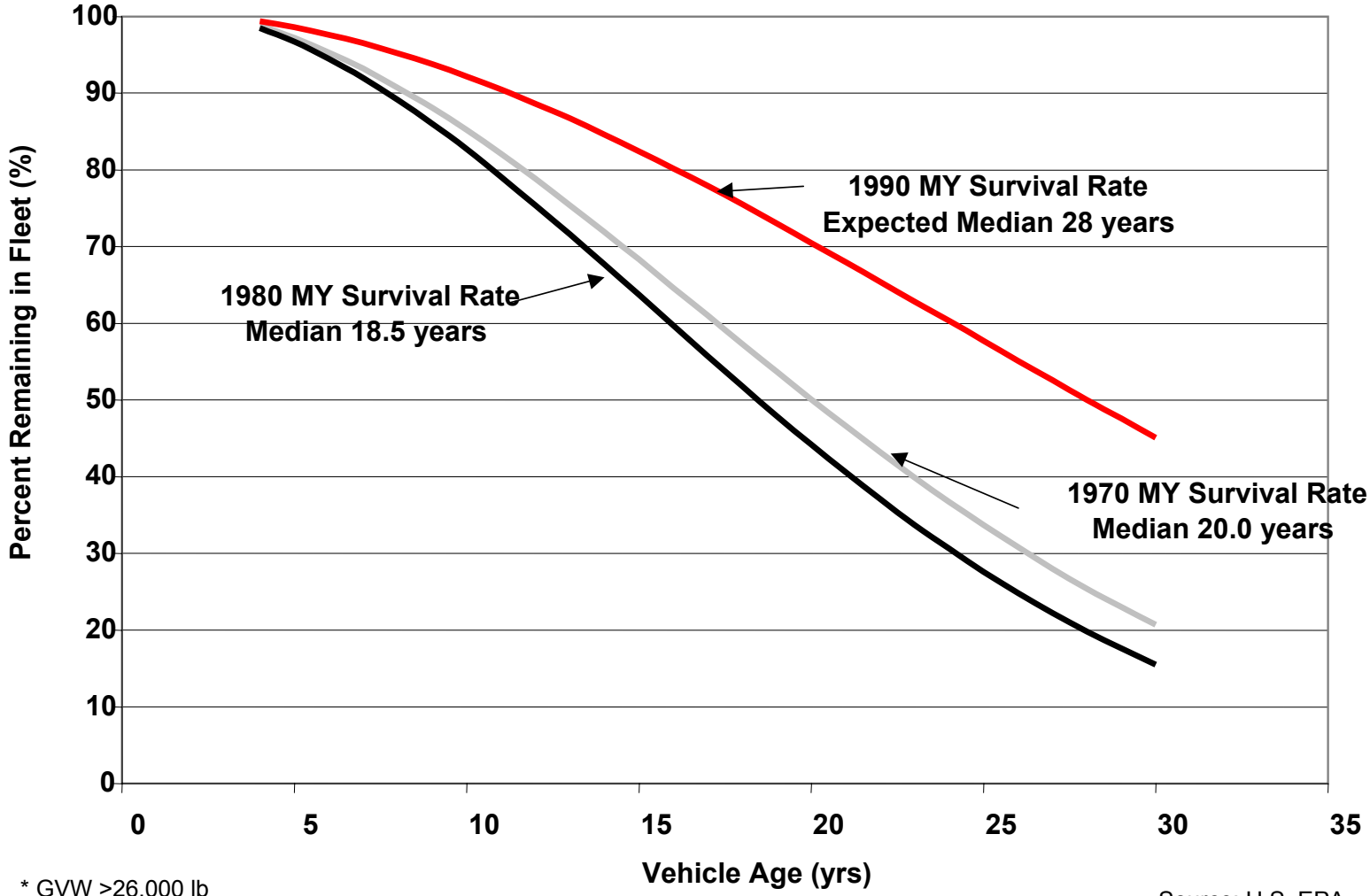
Nationwide fleet adoption will be driven by turnover rates for heavy-duty on-road vehicles*



* GVW >26,000 lb

Source: U.S. EPA

Scenarios for Fleet Adoption will be constructed based on cost-benefit

(numbers below are hypothetical.. .just for illustration)

	2007	2010	2012	2017
	Adoption as Percent of Sales			
Vehicle Upgrade (Aero, other)	**29%**	**34%**	**39%**	**49%**
Advanced Engine with VVA	0%	2%	5%	10%
Hybrid Electric Power-train	1%	2%	3%	5%
Bottoming Cycle	0%	0%	0%	2%
Package XXX	0%	0%	2%	4%
Package YYY	0%	2%	5%	10%
Package ZZZ	0%	0%	3%	6%

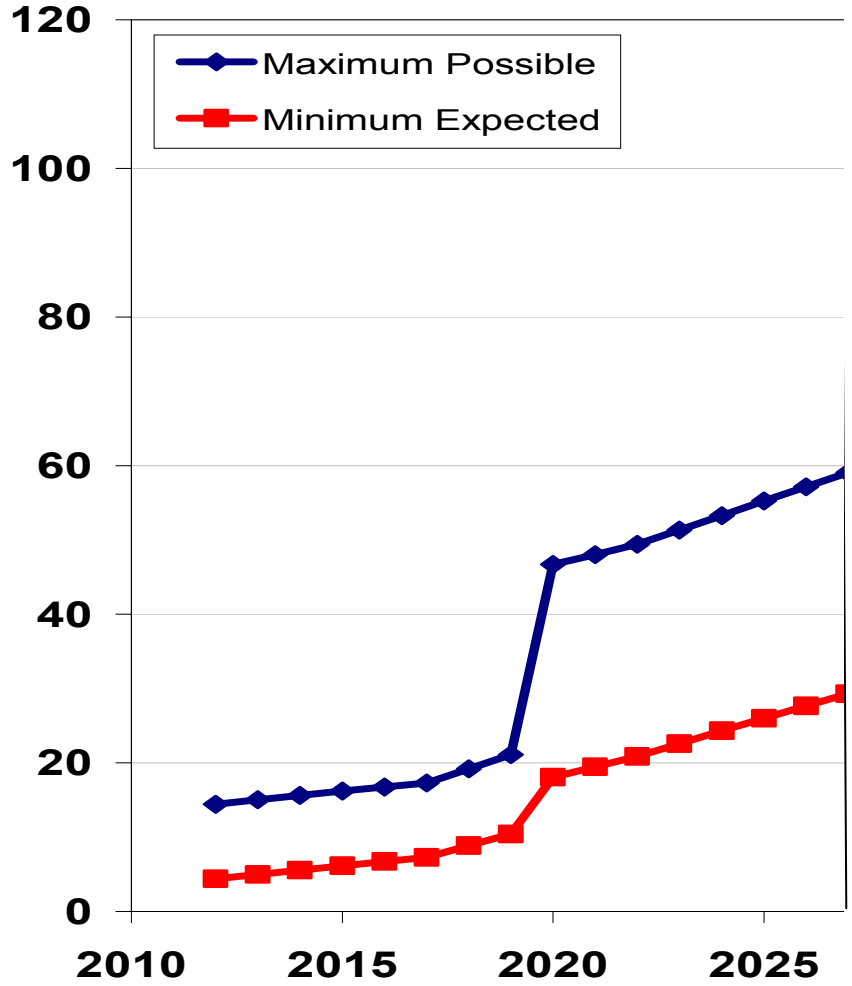
- **The winning technology for line-haul trucks is the one which offers the vehicle owner the most favorable business proposition for that duty cycle. Technologies that offer the most favorable economics (i.e., a combination of life-cycle cost and payback period) are more likely to be adopted.**
- **A 10-year ramp-up rate for market penetration, typical of this conservative industry, is assumed in this study, unless otherwise dictated by regulations.**

The adoption rate will differ for each fuel saving package…some considerations for replacement of on-Road HDVs:

- Do lower operational costs (e.g., maintenance, fuel economy benefit) offset initial investment? Lifecycle costs and payback period
- Screening of the targeted truck population for suitability is essential
  - –Savings real for the specific duty cycle?
  - –Is targeted end user group conducive to using / maintaining new truck properly?
  - –Infrastructure requirements
  - –Variability of driver workload and duty cycle; required horsepower

Expected nationwide diesel fuel reductions will be a fraction of what is theoretically feasible, in part because fleet turnover is gradual

hypothetical.. .iust for illustration:



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Adoption of Advanced High-Efficiency Trucks will occur if benefits exceed costs

- Truck OEMs will anticipate and shape the market
- Private Capital (suppliers, distributors, vehicle manufacturers, consumers, investors)
- Wild Card: Government incentives or regulations such as ARB proposed rules forcing fleet modernization and use of SmartWay certified truck purchases
- Wild Card: many line-haul trucks have bimodal lives
- Truck markets will require affordable new products
  - Higher cost technologies but fuel savings for generally lower life cycle costs
  - OEMs will need support to develop new products with the latest technology
- Industry and government commitment
  - Government needs to be involved over many years
  - Industry needs the resources and long term vision to make major shifts in the vehicle markets

Thank You For Your Attention!

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- **NESCCAF**
- **ICCT**

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