Impact of Program Goals on Hydrogen Vehicles:
Market Prospect, Costs, and Benefits

* H2V = { H2 ICE, FCV, FC PHEV }

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2012 DOE Fuel Cell Technologies Program

Annual Merit Review

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Project ID #: AN025

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Timeline

- **Start: Oct 1, 2011**
- **End: Sep 30, 2012**
- **50% complete**

Budget

- **Total project funding**
  - DOE share = $135k
  - No cost share
- **FY12 = $135k**

Barriers

- **Barriers addressed**
  - A. Future Market Behavior
  - B. Stove-piped/Siloed Analytical Capability
  - C. Suite of Models and Tools
  - D. Unplanned Studies and Analysis

Partners

- **Interactions / collaborations**
  - NREL
  - ANL
  - UC Davis, U. of Tennessee
  - Industry
- **Project lead**
  - Zhenhong Lin, ORNL

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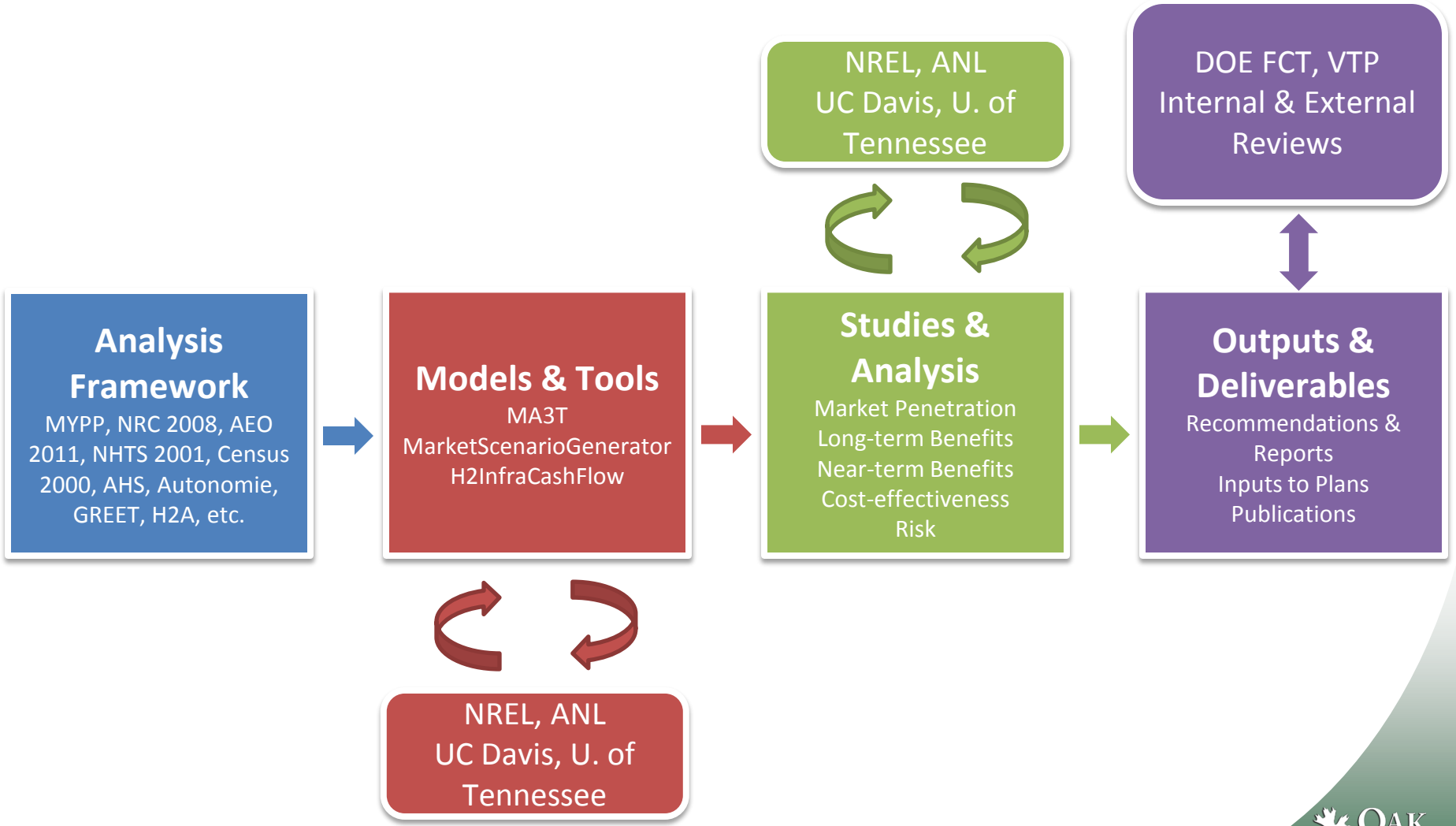


Relevance

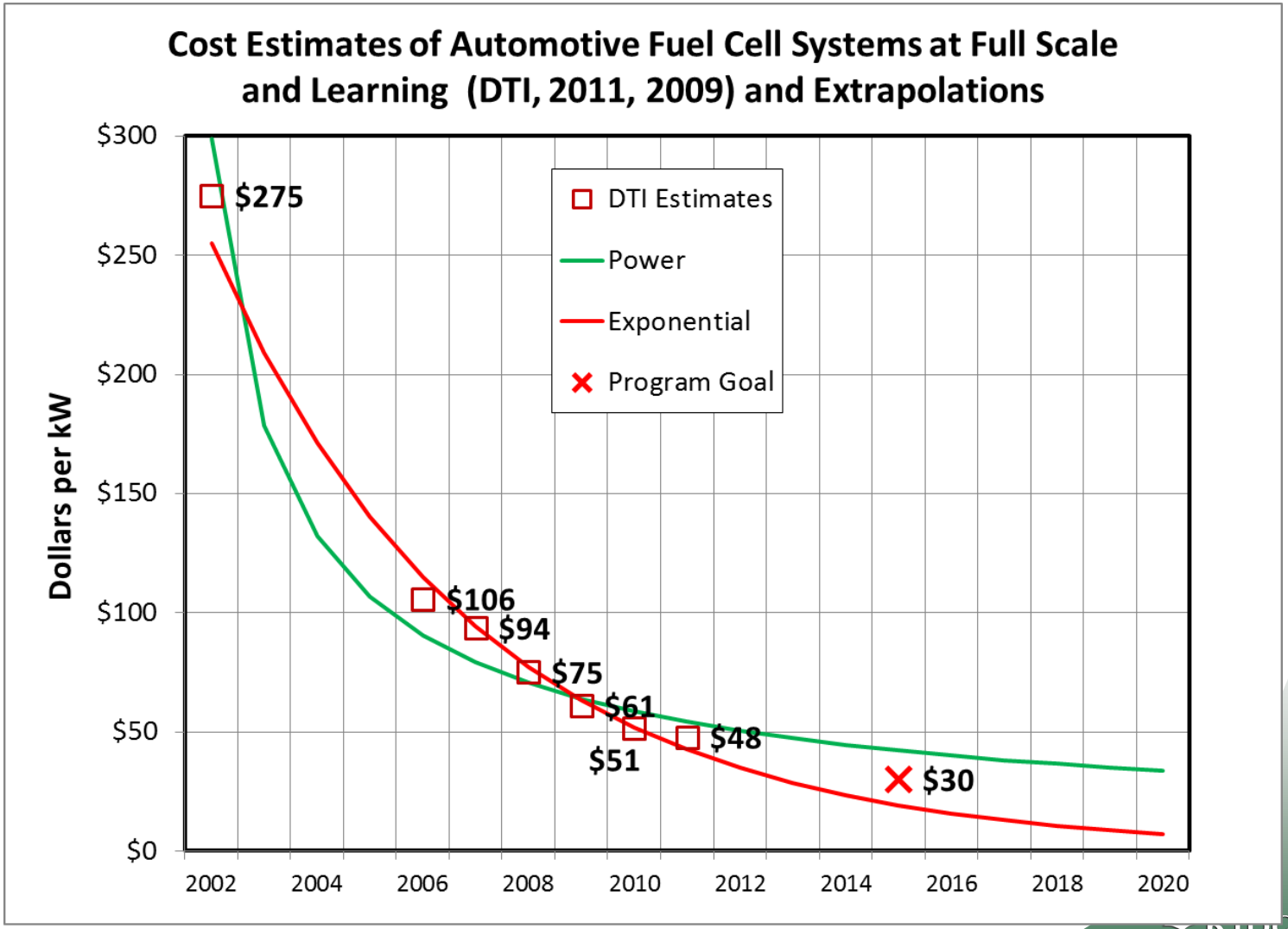
Estimate the impact of DOE program goals (PG) on the market prospect, costs and social benefits of hydrogen-powered light-duty vehicles (LDV)

DOE Barriers	Project Goals

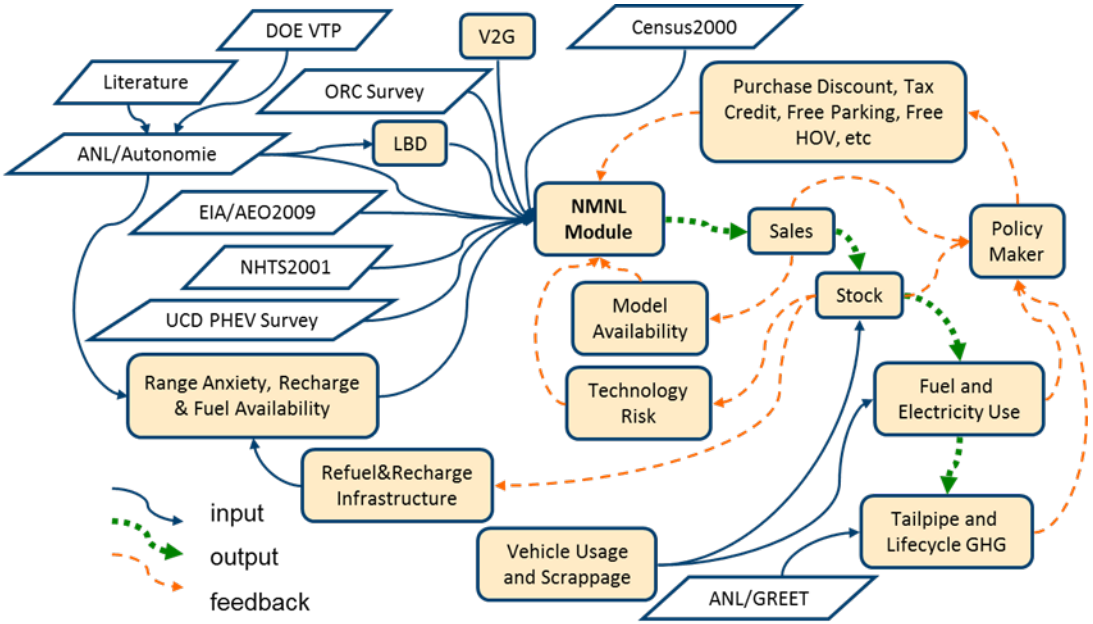
• Stove-piped/Siloed Analytical Capability
• Suite of Models and Tools
	• Conduct market analysis by integrating output of various DOE-sponsored and other federal projects, including:
	  • ORNL's MA3T model
	  • ANL's Autonomie model
	  • NREL's H2A model
	  • EIA's AEO projection
	  • DOT's NHTS database
	  • EPA's technology assessment

• Future Market Behavior
• Unplanned Studies and Analysis
	• Project market penetrations of H2 vehicles under varied assumptions of program goals for fuel cells, H2 storage, batteries, motors, and H2 supply.
	• Under different program goals scenarios, estimate social benefits and public costs, including:
	  • Petroleum use reduction
	  • Greenhouse gas reduction
	  • Zero-emission vehicle population
	  • Grid-connected vehicle population
	  • Public expenditure for infrastructure
	  • Public expenditure for vehicle purchase
	• Compare cost-effectiveness among scenarios

Not there yet, but we are on track to meet the target on fuel cell cost as well as other goals. How important is it to meet these goals?



ORNL's MA3T model is used to simulate the impact of DOE program goals on various metrics of the LDV transition.



- MA3T = Market Acceptance of Advanced Automotive Technologies
  - A discrete choice model
- project sales of 40 vehicle technologies
  - Conventional and hybrid ICE, PHEV, H2 ICE, FCV, FC PHEV, NGV, BEV
- 1458 consumer segments: region, area, driver, adopter, home and work charge
  - Consumers are assumed to choose what maximize their utility
- daily VMT variation for accurate energy use and range anxiety
- representation of both refueling and recharging infrastructure barriers

41 different exogenous projections of technology status relative to program goals

- **Technology**

	Unit	Cost (Year) "Base"	Cost (Year) "ProgramGoal"
H2, Delivered at Pump	$/gge	**3.8** (constant)	**2.1** (2017)
H2 On-board Storage	$/kWh	**10** (2050)	**10** (2030), **8** (2045)
Fuel Cell System	$/kW	**60** (2030)	**30** (2015), **18** (2045)
PHEV40 Battery	$/kWh	**450** (2045)	**300** (2014), **270** (2017)
EV Battery	$/kWh	**375** (2030)	**150** (2020)

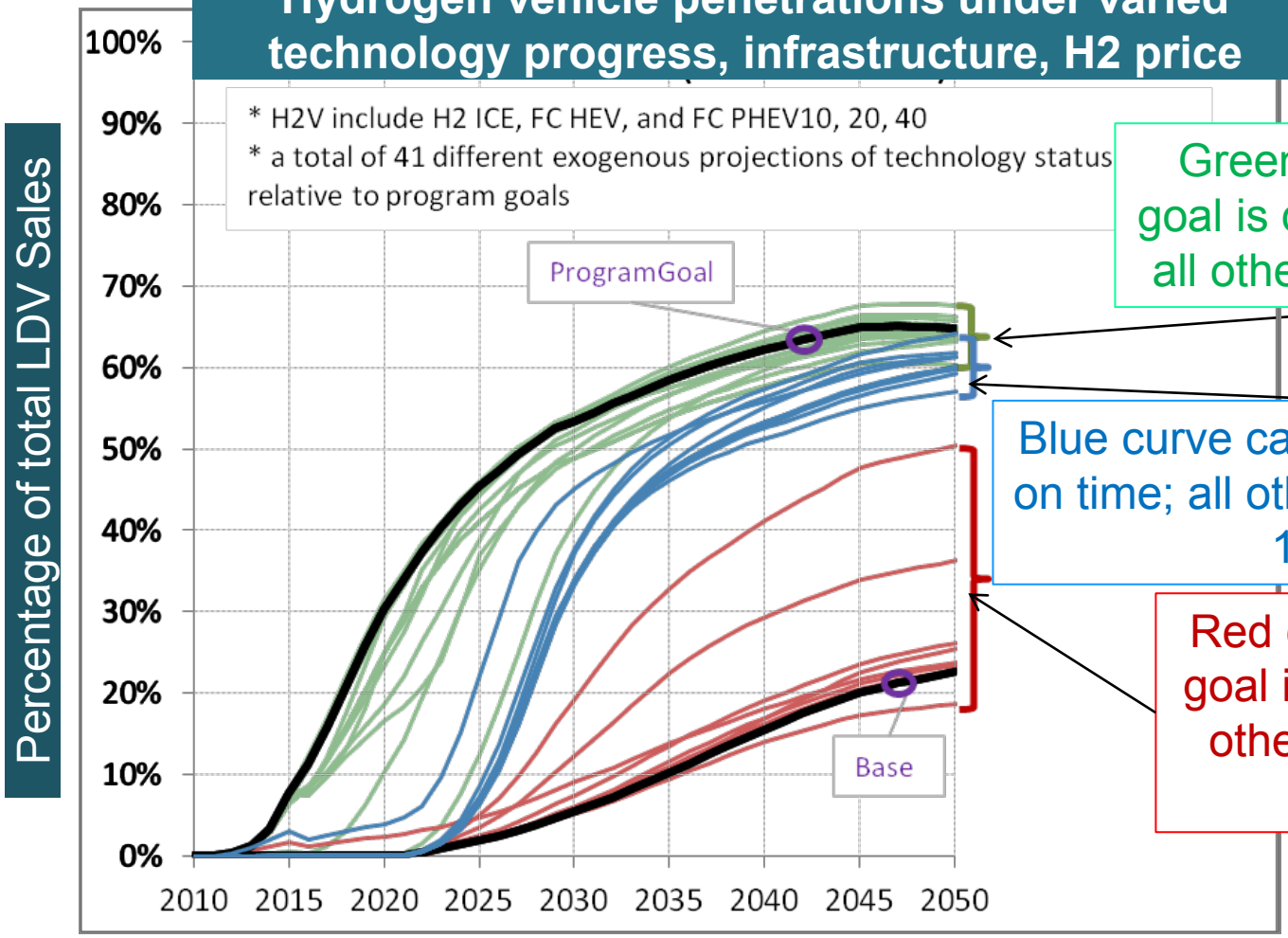
  - Program goals are highlighted in red

- **Assumed public support**
  - Includes existing ARRA vehicle subsidy AND H2 infrastructure subsidy

More details in backup slide #19

1. H2V penetration ranges from 20% - 70% by 2050
2. Program goals important for H2V market success
3. Long-term H2V penetration mostly affected by FC and H2 cost; for early market, infrastructure deployment is key

Hydrogen vehicle penetrations under varied technology progress, infrastructure, H2 price



Green curve cases: one goal is delayed by 10 years; all other goals met on time

Blue curve cases: one goal is met on time; all other goals delayed by 10 years

Red curve cases: one goal is met on time; all others with baseline technology

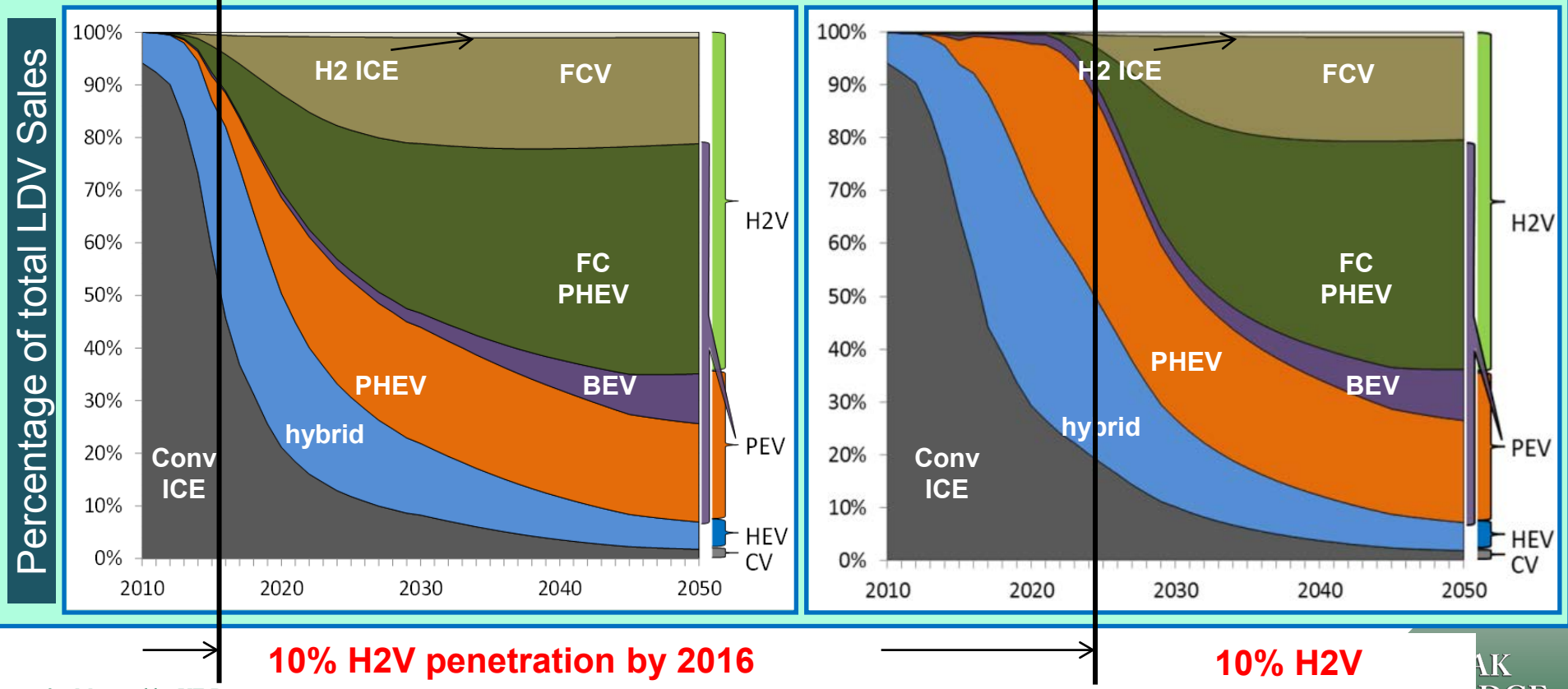
More details in backup slide #22

1) If all goals met, both H2Vs and PEVs could dominate the market. 2) FC PHEVs appear to have significant market potential. 3) infrastructure delay causes H2V market delay

Market penetrations when all goals met on time

w/ no infrastructure delay, 10% penetration by 2016

10-yr infrastructure delay causes 10-yr penetration delay

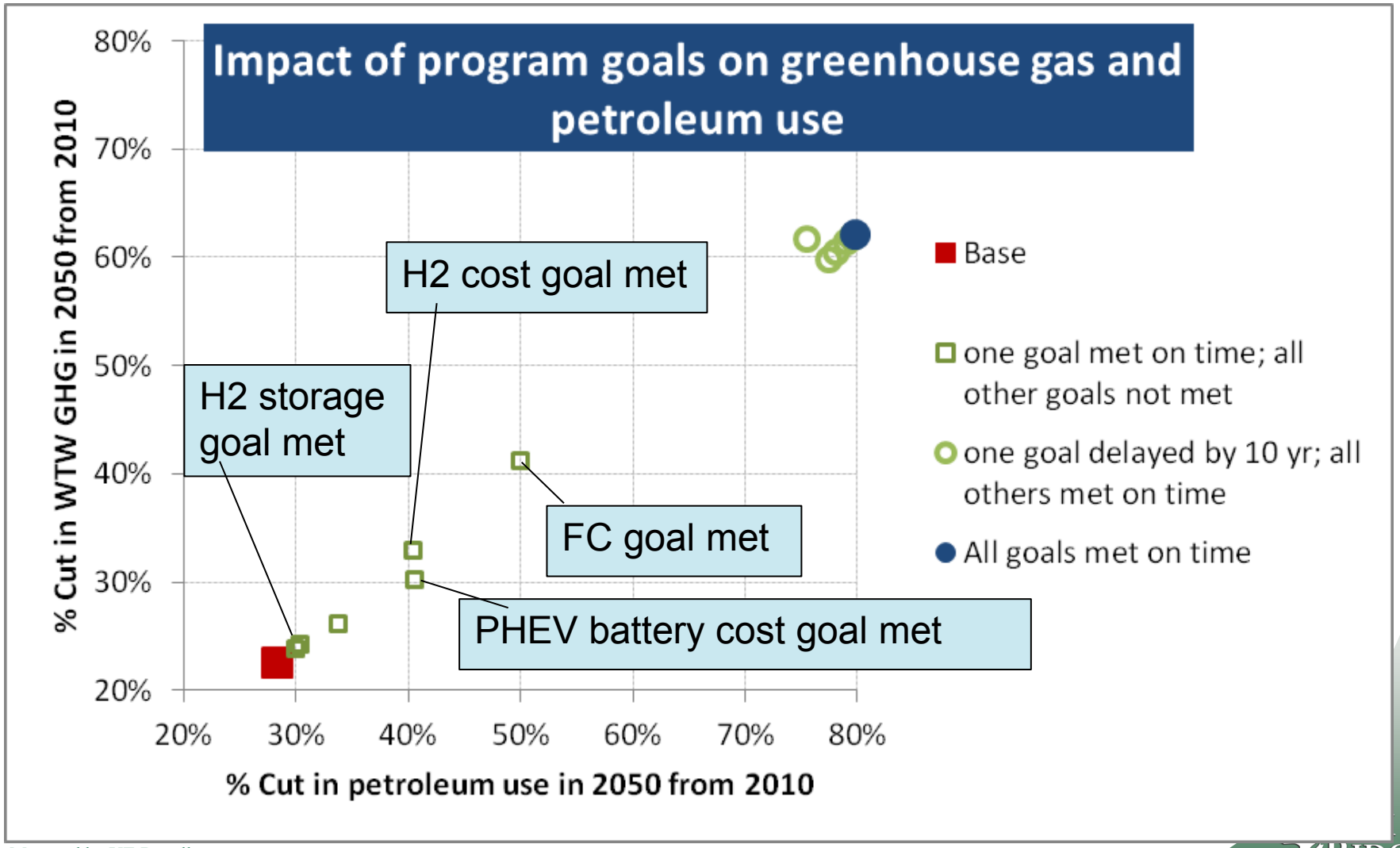


10% H2V penetration by 2016

10% H2V penetration by 2025

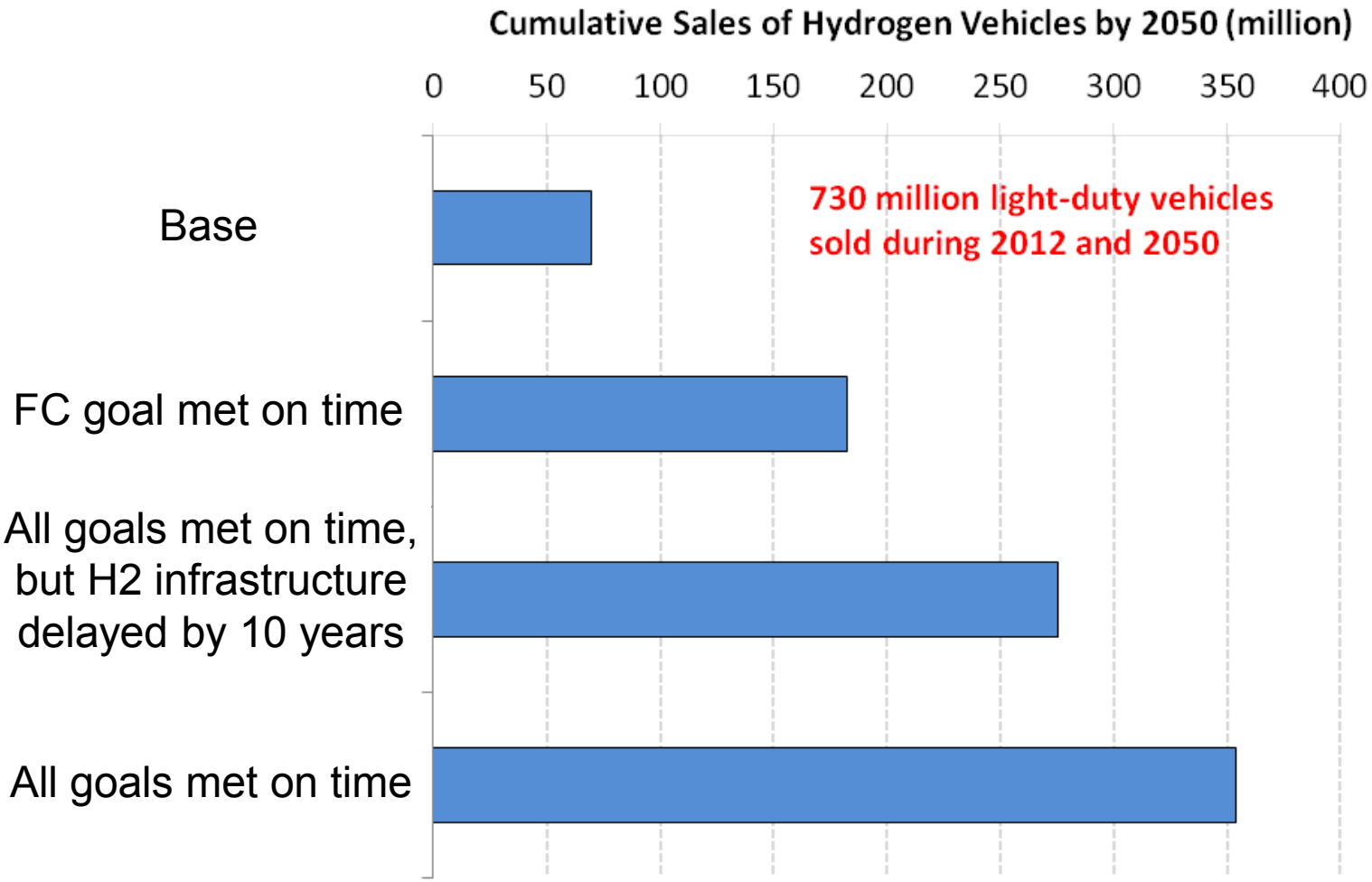
More details in backup slide #23

1) Meeting all goals allows ~80% cut in petroleum use and ~60% cut in GHG by 2050. These cuts are robust against one-goal delay. 2) FC goal results in the largest impact.



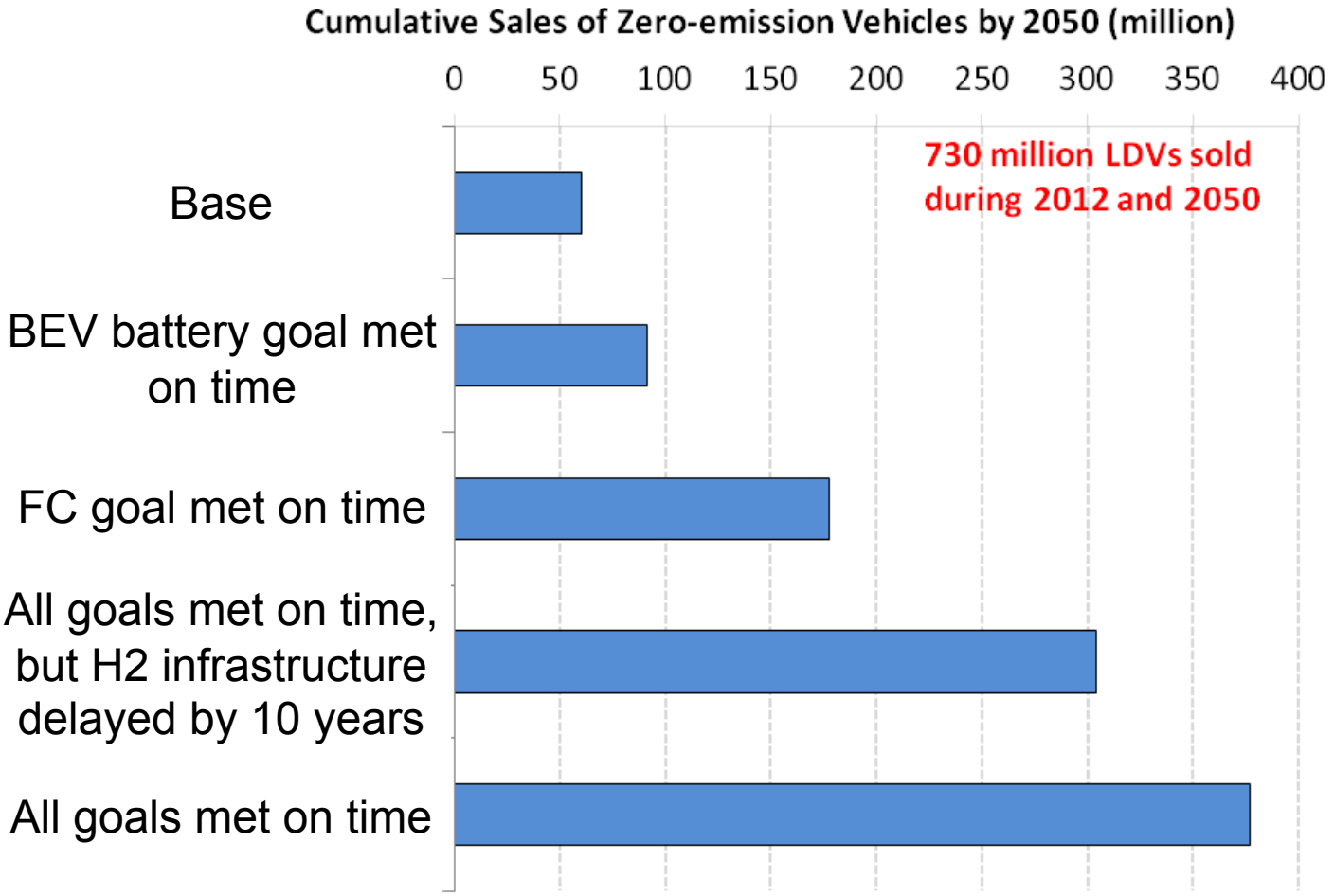
More details in backup slide #25, #26

To bring more H2Vs to the road by 2050, FC cost and H2 infrastructure are the key

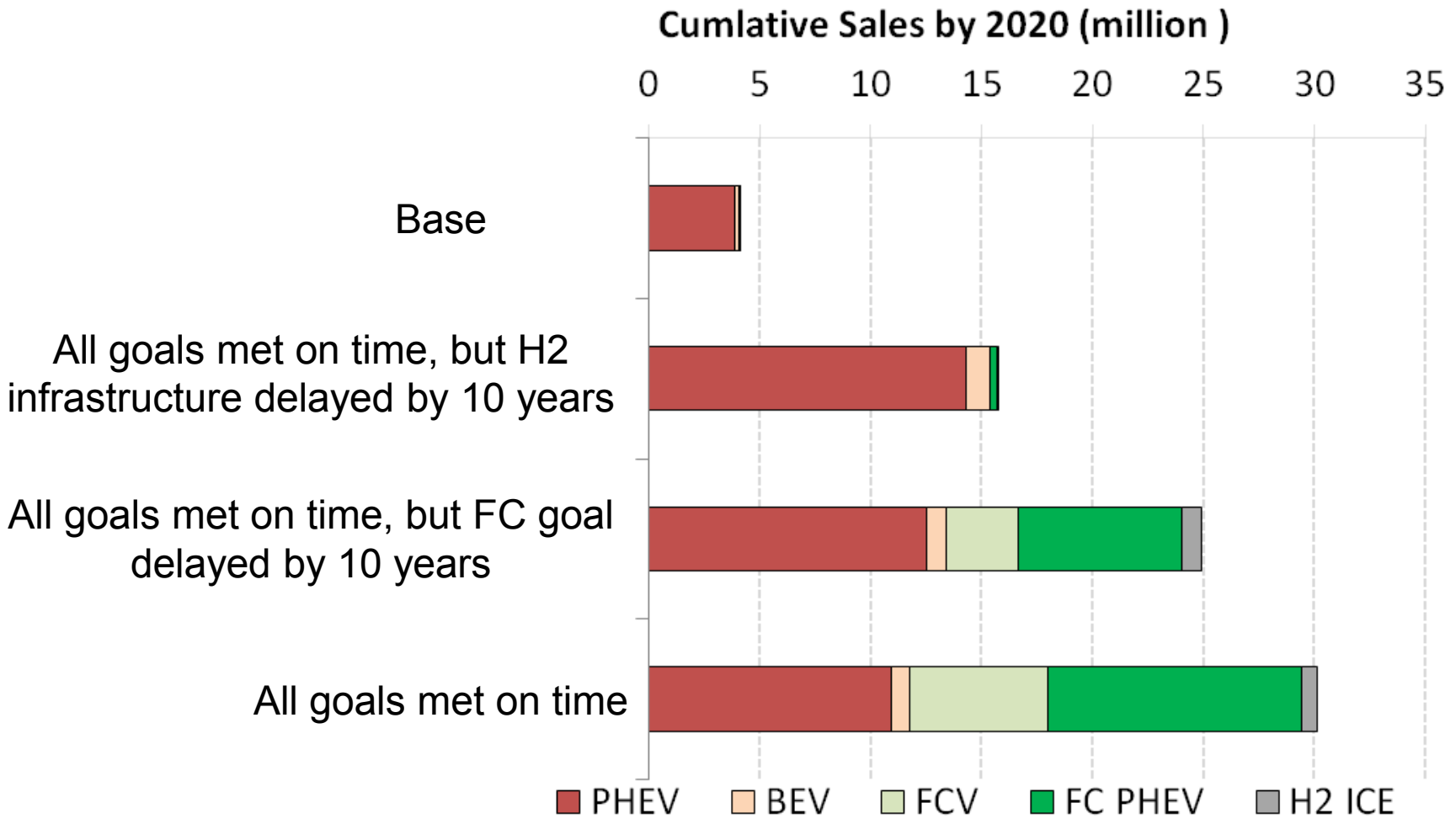


More details in backup slide #27, #28

1) If all goals met on time, about half of all LDVs sold by 2050 are estimated to be ZEVs; sensitive to H2 infrastructure and FC goal. 2) largest impact by FC goal on ZEV sales

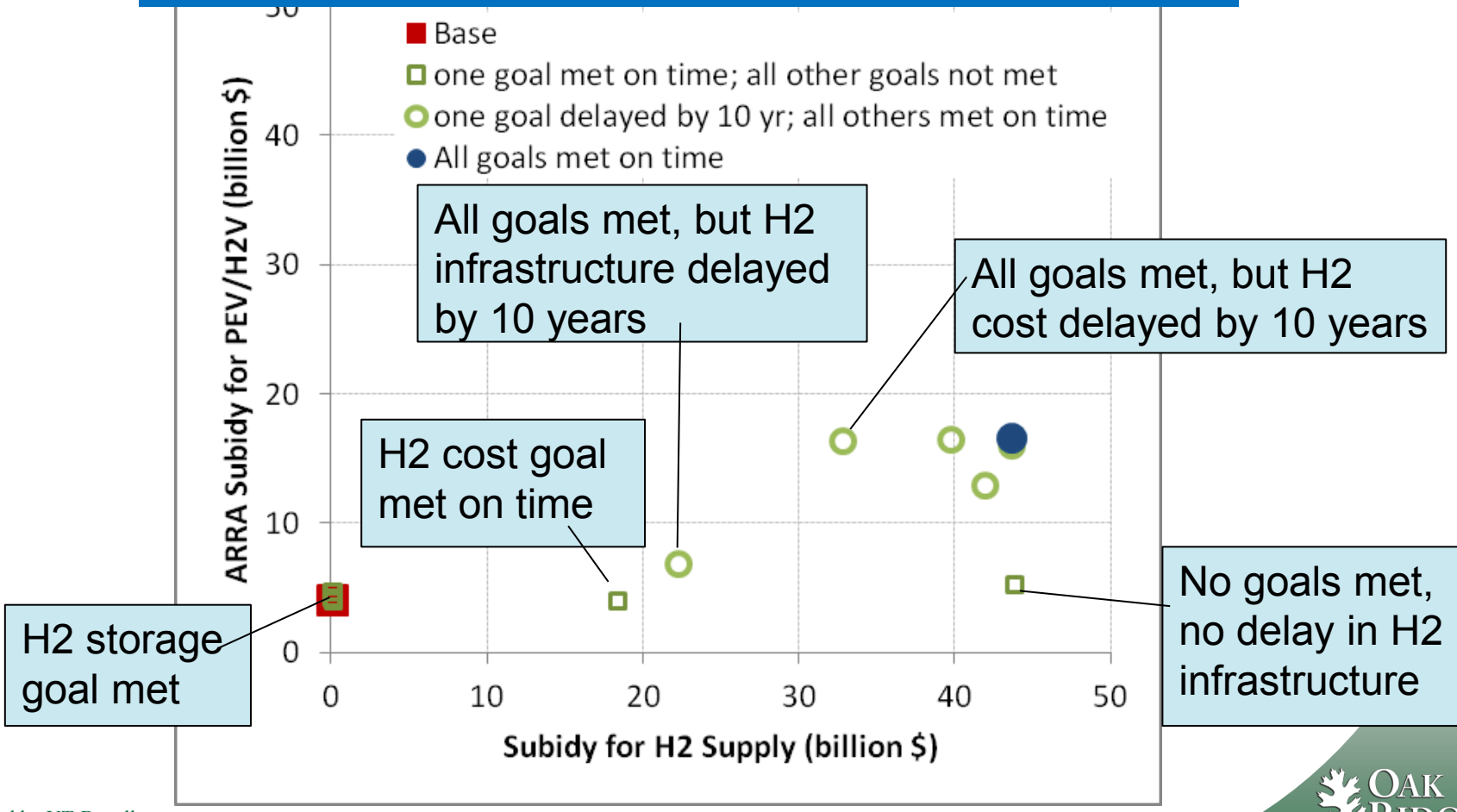


1) Achieving most program goals can substantially increase number of alt. fuel vehicles sold by 2020; 2) near-term H2V market is sensitive to FC goal and H2 infrastructure



If most goals met on time, the transition requires 30-50 b$ of H2 subsidy and 10-20 b$ of vehicle subsidy through 2050

Required public support



More details in backup slide #28-29

- Using the MA3T model, 41 scenarios were used to estimate the impact of program goals on market prospect, social benefits, required gov't support, and cost-effectiveness of LDV market transition.
- The program goals for the hydrogen delivered cost and fuel cell system cost have the biggest impact on the success of hydrogen technologies.
- The sooner the program goals are met, the larger the oil/GHG reduction benefits
  - The success of hydrogen technologies does not require all DOE program goals to be met on time, but key goals need to be met w/o major delay
  - If only one goal is missed, most of the GHG/oil benefits can still be achieved.

The project includes input from and collaboration with other national labs, industry and universities.

- Collaboration Partners
  - NREL: developed the H2A model, the source of hydrogen cost estimates.
  - NREL and UC Davis: provided key insights on fuel accessibility modeling
  - ANL: developed the H2A delivery and Autonomie models and share data
  - Industry (Ford, Nissan, Honda): interaction including exchange on fuel cell vehicle early market strategy and daily VMT variation
  - University of Tennessee: share vehicle data that allows model calibration.

THANK YOU

BACK-UP SLIDES

41 different exogenous projections of technology status relative to program goals

- **Technology**

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  - Program goals are highlighted in red

- **Public support**
  - includes ARRA subsidy and H2 infrastructure subsidy
  - The American Recovery and Reinvestment Act (ARRA) vehicle subsidy depends on battery capacity, but FCV and FC PHEV assumed to receive the $7500 maximum due to zero emissions.
  - H2 cost is independent of H2 price; assume a 0.85 scaling factor; actual utilization is endogenous to determine the actual delivered cost; the gap between cost and price is balanced by subsidy

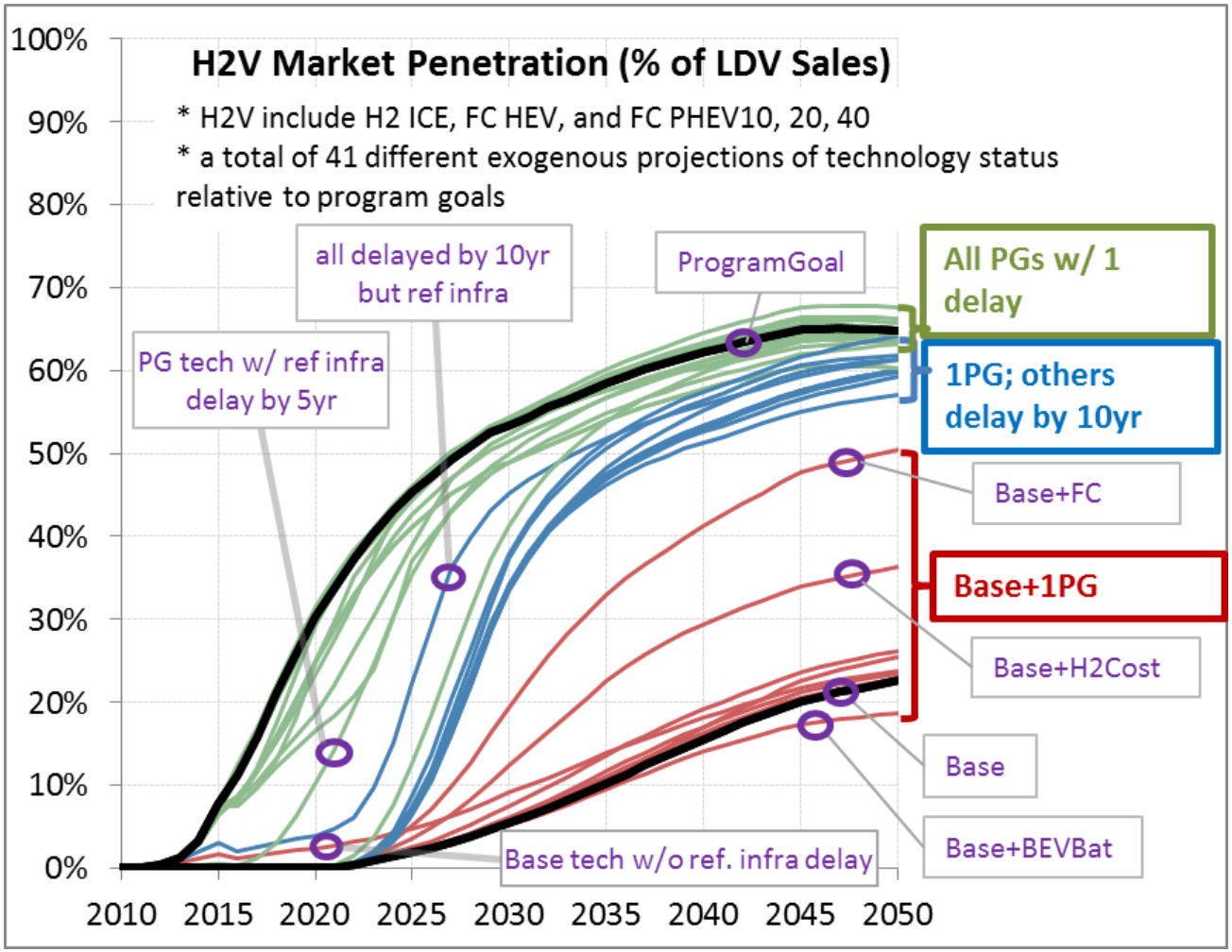
Scenario definition and label --1

- "Base"
  - Base technologies; both refueling and recharging infrastructure deployments delayed by 10yr relative to "ProgramGoal"
- "ProgramGoal"
  - all goals met on time; 50% availability of recharging and H2 refueling by 2050
- "PGdb10+???", "PG-??-db5", "PG-??-db10", "Base+????"
- "+" means a positive exception; "-" means a negative exception
- db5 or db10="delayed by 5 or 10 years"; PG= program goal; H2S= hydrogen on-board storage; BEVBat =battery for battery electric vehicles; P40Bat=battery for PHEV40; FC=fuel cell; RefInfra=H2 refueling infrastructure; $2H2by2020=H2 priced at $2/kg until 2020;

Scenario definition and label --2

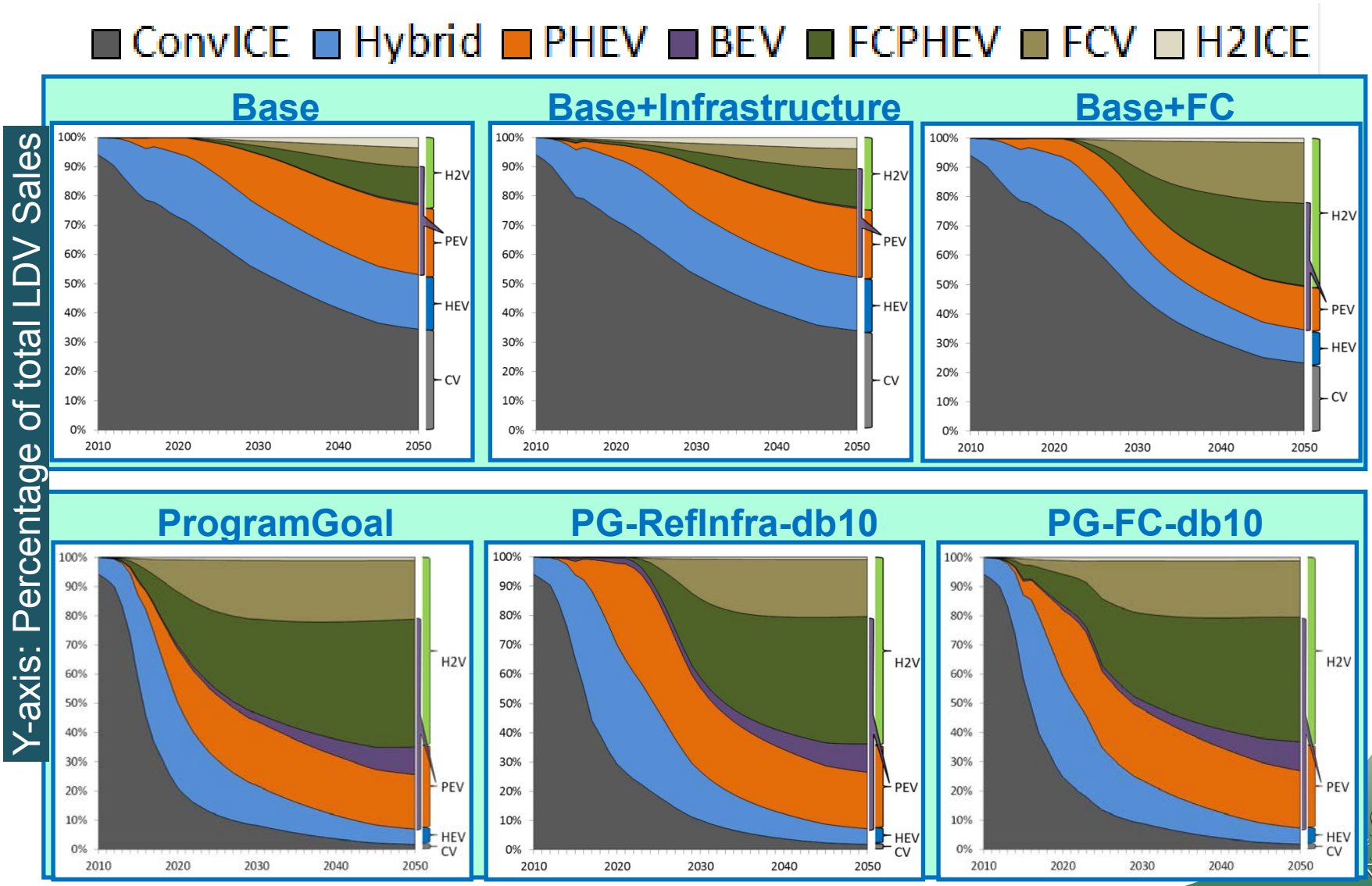
- "PGdb10+???"
  - All goals and infrastructures delayed by 10 years relative to "ProgramGoal", except that the technology/infrastructure specified by ??? is the same as in "ProgramGoal"
  - For example, "PGdb10+RefInfra" refers to the case where all goals/infrastructure are delayed by 10 years, except H2 refueling infrastructure is deployed as in the "ProgramGoal" case
- "PG-??-db5" and "PG-??-db10"
  - all goals/infrastructure are met on time except ??is delayed by 5 year or 10 years
  - E.g. "PG-H2S-db5" means the case where all goals/infrastructure are met on time except hydrogen onboard storage technology is delayed by 5 year
- "Base+????"
  - all goals/infrastructure are the same as in the Base case, except that the technology/infrastructure specified by ???? is the same as in "ProgramGoal"
  - "Base+FC": only FC goal met on time, all others with Base tech status

1. H2V penetration ranges from 20% - 70% by 2050
2. H2V market dominance does not require all PGs be met
3. Long-term H2V penetration mostly affected by FC and H2 cost; for early market, infrastructure deployment is key

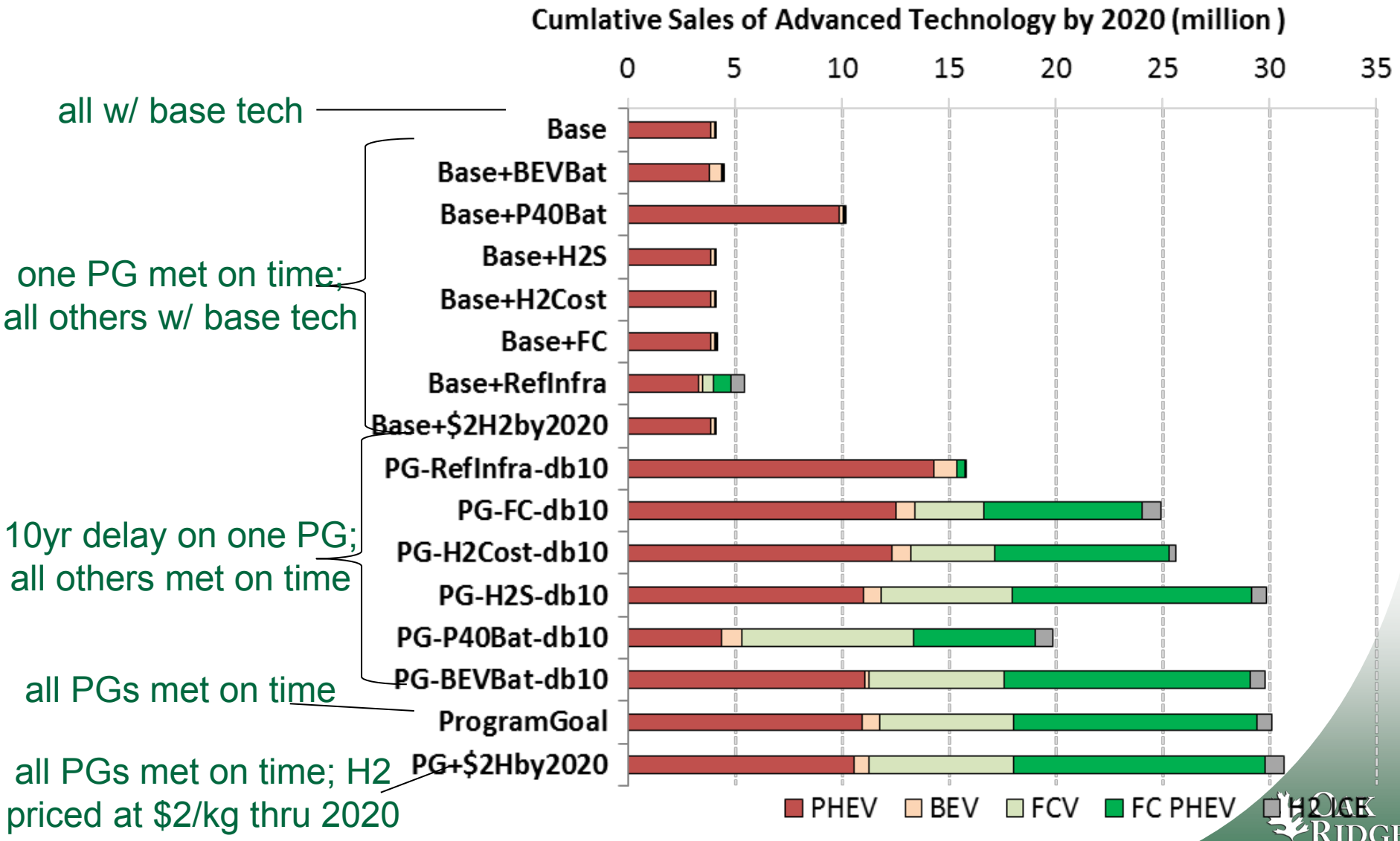


Technical Accomplishments and Progress---Market Prospect

1. If all PGs met on time, both H2V and GCVs could dominate the market.
2. Plug-in fuel cell vehicles appear to have significant market potential.
3. H2V only occurs after H2 infrastructure deployment

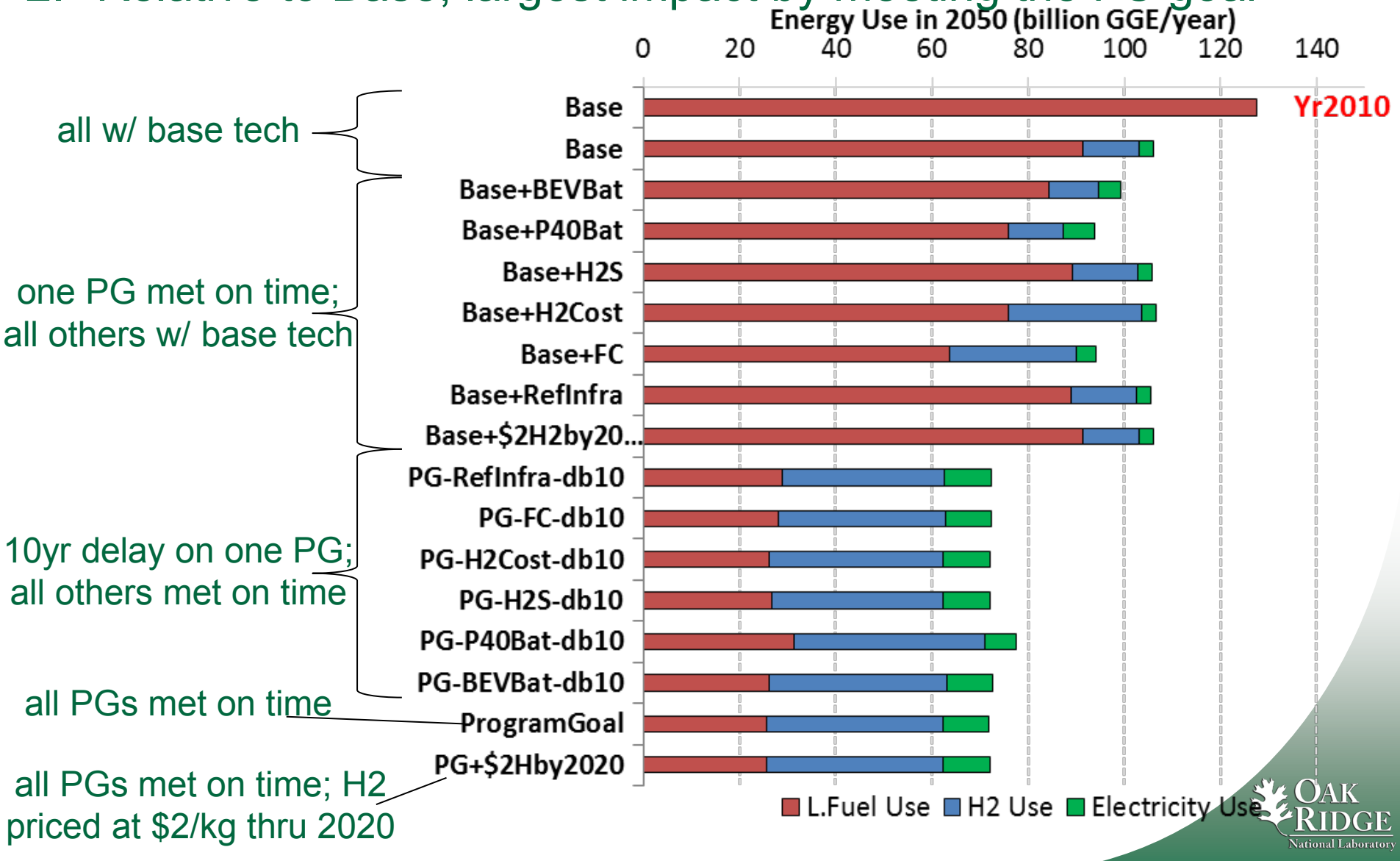


Achieving most program goals can substantially increase number of alt. fuel vehicles sold by 2020



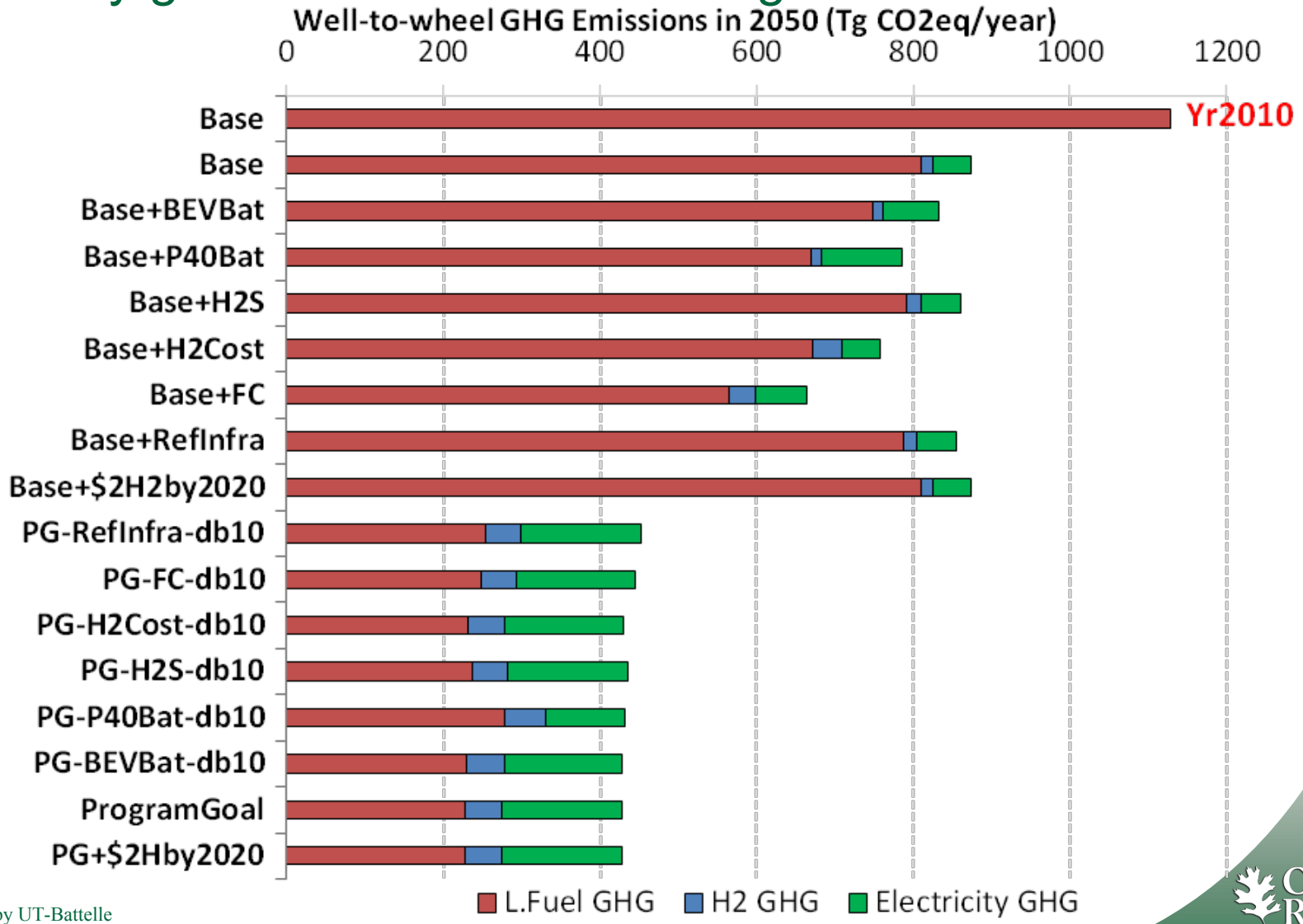
Energy Security – 2050 petroleum use

1. 80% cut if all goals met; robust against one-goal delay
2. Relative to Base, largest impact by meeting the FC goal



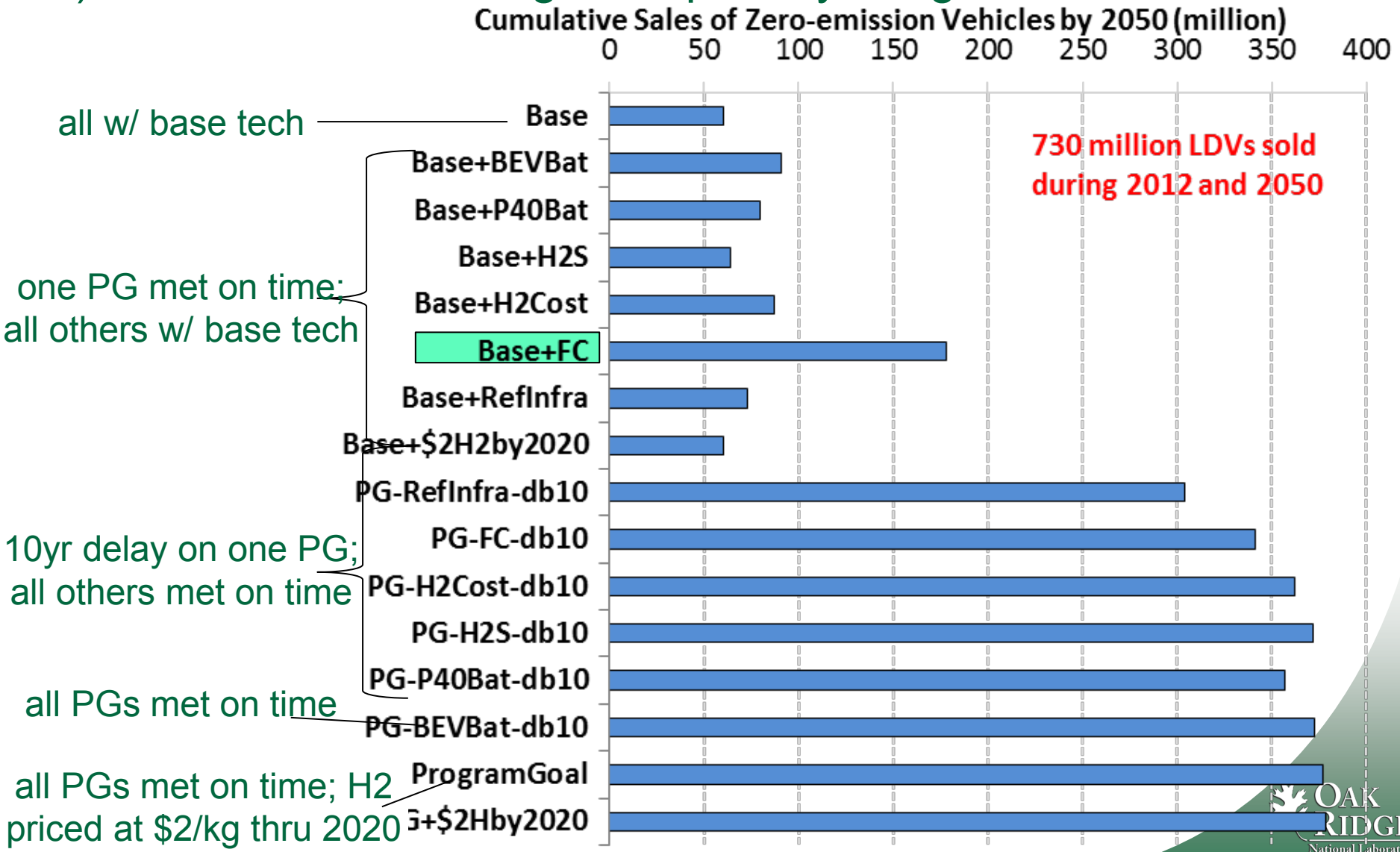
Climate Change—2050 GHG emissions

1. 62% cut if all goals met; robust against one-goal delay
2. Possibly greater cut w/ biofuel and grid de-carbonation



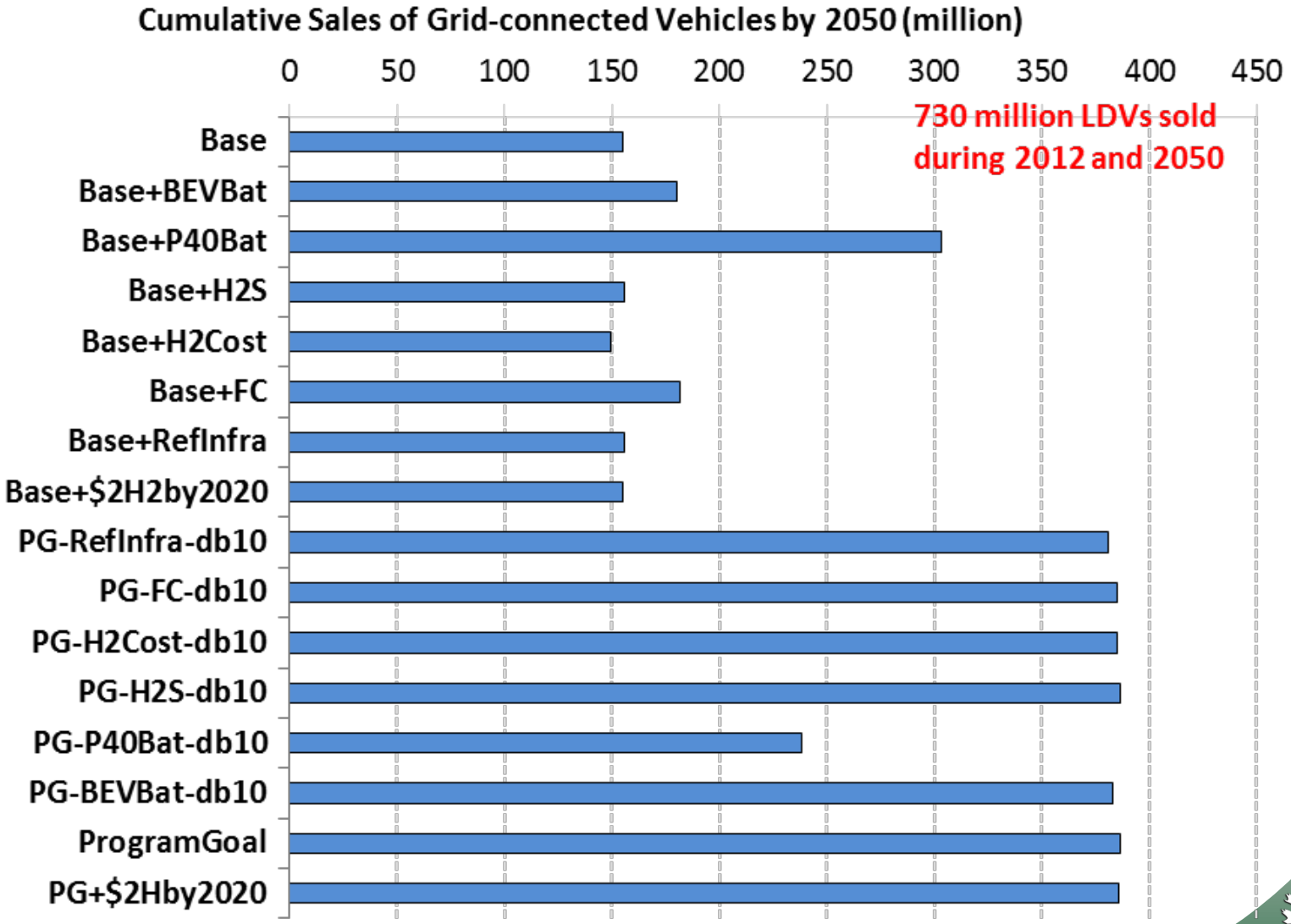
Technical Accomplishments and Progress---Long-term Benefits

1) If all goals met on time, about 53% of all LDVs sold are zero-emission vehicles; sensitive to H2 infrastructure and FC goal.
2) Relative to Base, largest impact by FC goal on ZEV sales



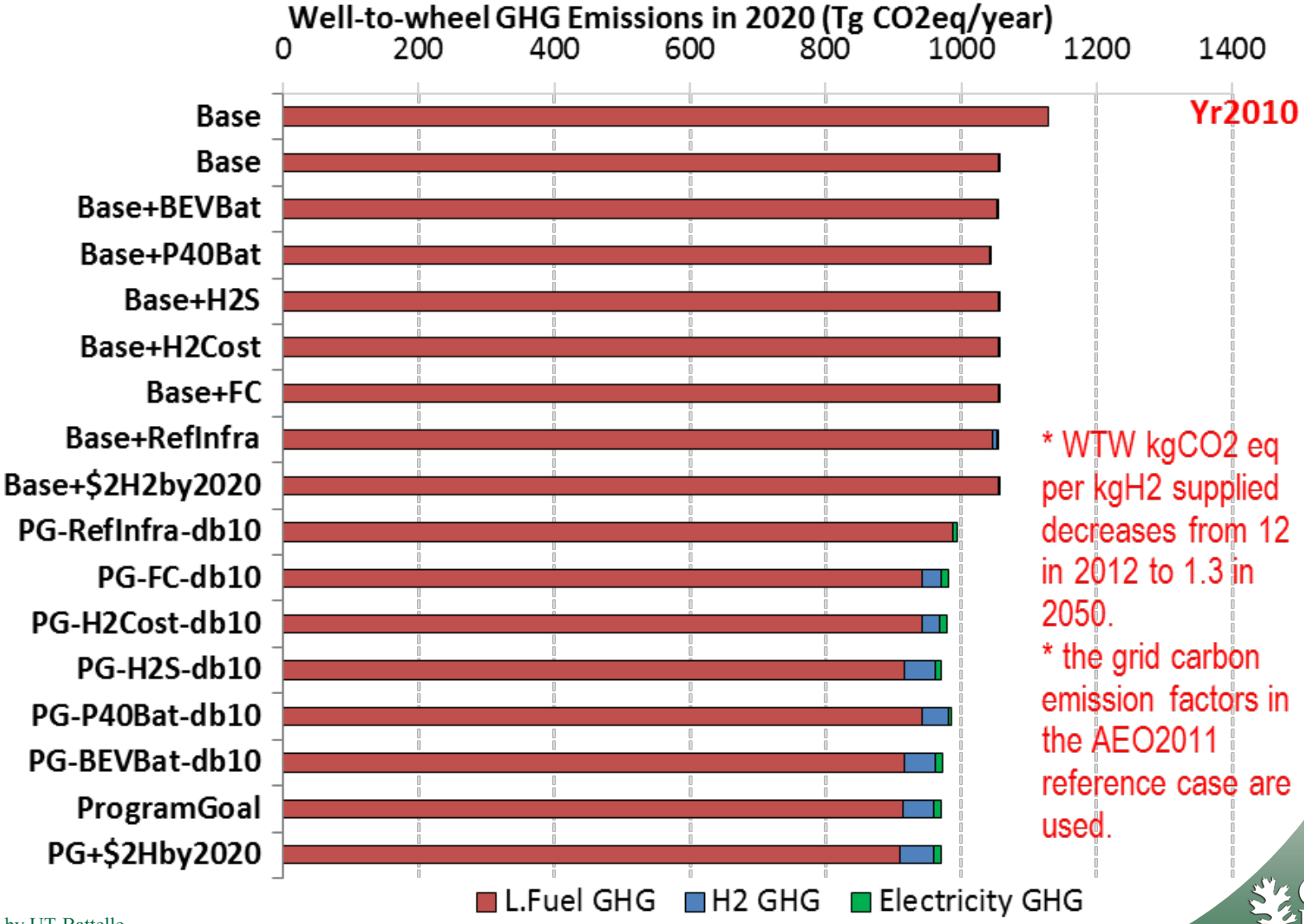
Energy Security—cumulative sales of grid-connected vehicles

1. Amounted to 53% of all LDVs sold; sensitive to PHEV battery cost
2. W.r.t Base, largest marginal impact also by PHEV battery cost



Near-term GHG emissions cut

1. About 15% reduction in annual GHG by 2020 if all goals met on time
2. The reduction potential could be larger w/ bio-fuel and grid decarbonization.



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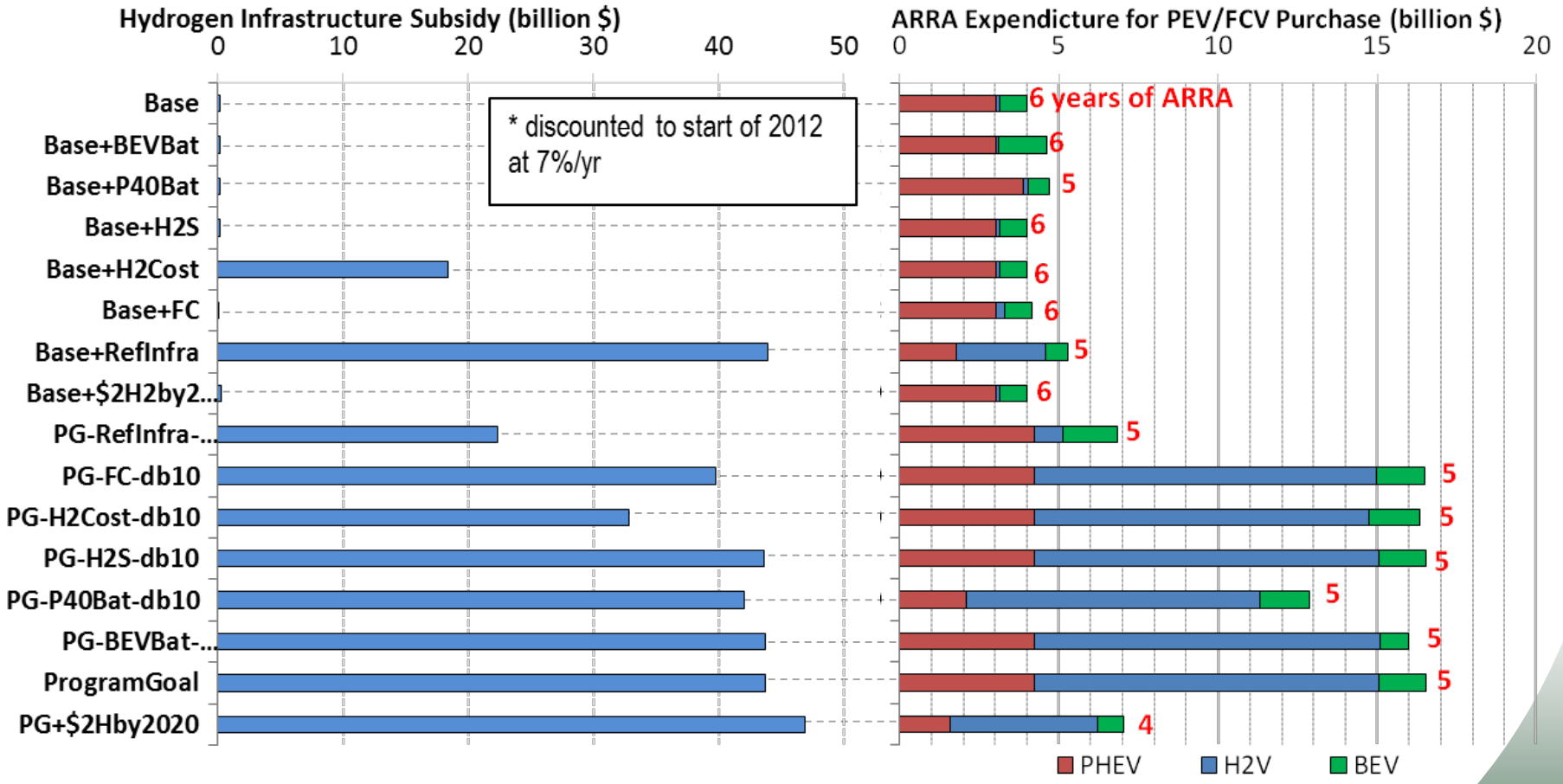

Competing for ARRA Tax Credit

How many of which technologies receive ARRA subsidy depends on technology progress and timing of subsidy expiration