New York State
Cap-and-Invest (NYCI) Program

Inputs Annex on NYCI Modeling Sectors

September 2023, Revised February 2024

DRAFT

NEW YORK STATE | NYSERDA | Department of Environmental Conservation

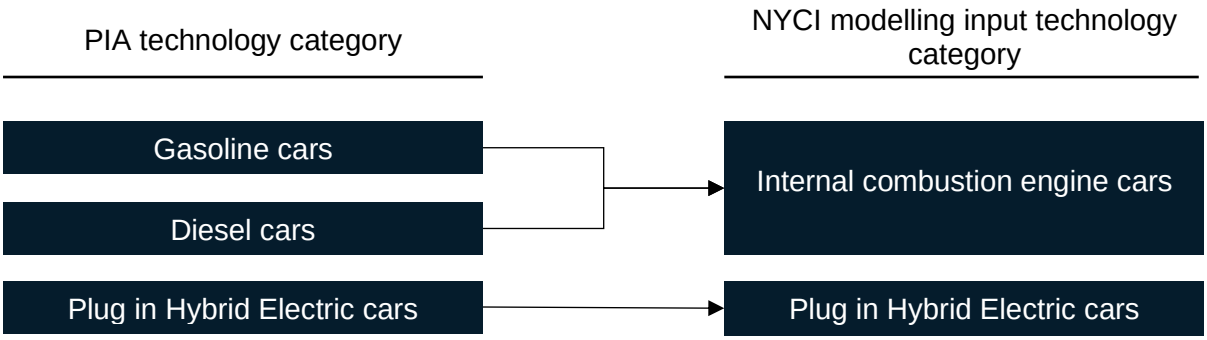
1. Introduction

On June 20, 2023, NYSERDA presented *Cap-and-Invest Analysis Inputs and Methods* for the potential New York State Cap-and-Invest (NYCI) program. This document provides supplemental data regarding that methodology. The NYCI analysis framework seeks to leverage input assumptions that were carefully developed and vetted with the public and expert stakeholder panels as part of the Scoping Plan and Integration Analysis process that concluded in December 2022. The modeling team for this NYCI analysis relied on the core cost input assumptions found in Annex I of the Scoping Plan for most of the core cost assumptions developed for the NYC analysis.

This document outlines the approach for deriving assumptions regarding capital expenses (capex) and operating expenses (opex) for NYCI modelling by aggregating similar assumptions from the Pathways Integration Analysis (PIA) prepared as part of New York's Scoping Plan.[1] PIA produced the cost and energy estimates[2] for a more detailed set of technology categories than the categories NYCI modeling can apply for its inputs; therefore, the data for technology categories from PIA are aggregated to the required level for NYCI modeling. This document further sets out the assumptions for renewable fuel supply in relation to the PIA.

Exhibit 1 illustrates this process for a non-exhaustive example of car technologies. As shown in Exhibit 1, NYCI modeling uses a technology taxonomy with relatively limited resolution (e.g., internal combustion engine cars instead of gasoline and diesel cars). Therefore, a many-to-one mapping is required to link the PIA technology categories to NYCI modeling categories[3].

Exhibit 1



Section 2 outlines the aggregation approach used and illustrative examples of each step.

Section 3 provides a detailed table of the mapping from each PIA technology category to the matched NYCI modelling technology category.

Section 4 describes the modeling approach and assumptions on blending of renewable fuels.

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[1] New York State Climate Action Council. 2022. "New York State Climate Action Council Scoping Plan." climate.ny.gov/ScopingPlan

[2] The relevant estimates are unit capex, fuel consumption factors and fuel prices

[3] There is one exception to this, which is space heating. For space heating, the NYCI modelling uses inputs which vary with the building shell type (defined by the categories from PIA: basic shell, deep shell and reference shell). Thus, each space heating technology category is mapped to three distinct NYCI modelling categories

2. Approach to technology category aggregation

Translating PIA capex and opex into inputs for NYCI modelling involves four steps:

1. **Mapping:** conduct a many-to-one mapping of technology categories from the PIA to the technology categories under the NYCI modelling taxonomy
2. **Deriving annual opex:** for each technology category under the PIA taxonomy, NYCI modeling uses average annual costs. To develop this from PIA inputs, multiply average annual technology fuel consumption by an assumed fuel price to obtain an estimated annual opex.
3. **Weighting:** for each technology category under the NYCI modeling taxonomy, aggregate corresponding PIA technology categories into a weighted average cost, where weights are based on their technology mix under the updated PIA Reference Case.
4. **Unit conversion:** convert PIA units to NYCI modelling units

2.1. Mapping

As the PIA technology categories are more detailed than those for the NYCI modelling, each NYCI modelling category is mapped to one or more PIA technology categories. See Section 3 for the mapping of PIA to NYCI modelling technology taxonomies.

2.2. Deriving opex

To ensure consistency with PIA assumptions, technology opex can be derived by multiplying the fuel consumption for each technology by the respective fuel's retail price[4], as follows:

$$Opex_{(technology)} = Fuel\ consumption_{(technology)} \times Fuel\ price_{(technology)} \quad \text{(Equation 1)}$$

Example 1: Deriving opex for gas heating in residential buildings

Opex (conventional gas heating unit)	=	100	×	2	=	200
Description:		Fuel consumption of gas heating unit		Gas fuel price		Opex for conventional gas heating unit
Unit:		MJ/device/year		$/MJ		$/device/year

2.3. Weighting

A weighted average must be constructed to aggregate the capex or opex of the more detailed PIA technology categories to a single value for each NYCI modelling technology category. The weighting used for the average is the respective PIA technology's share in the 2020 technology mix of the NYCI modelling technology. The average expenditure is calculated as follows:

[4] Fuel price assumptions are aligned with PIA where data is available, and supplemented where necessary

$$\boldsymbol{NYCI\ modelling\ expenditure} = \sum_{\boldsymbol{technology}} \boldsymbol{Share\ of\ 2020\ technology\ mix_{(technology)}} \times \boldsymbol{expenditure_{(technology)}} \quad \text{(Equation 2)}$$

Where expenditure is either opex or capex.

Example 2: Calculating weighted average expenditure for gas heating in residential buildings

residential gas heating expenditure	=	(0.75	×	200)	+	(0.25	×	300)	=	225

Description:	Weight for conventional gas heating unit	Opex for gas heating unit	Weight for efficient gas heating unit	Opex for efficient gas heating unit	Opex for gas heating
Unit:	% of 2020 stock	$/device/year	% of 2020 stock	$/device/year	$/device/year

2.4. Unit conversion

NYCI modelling sometimes uses different units to the PIA and hence a conversion is required, as follows:

$$\boldsymbol{Expenditure\ in\ NYCI\ modelling\ unit} = \boldsymbol{NYCI\ modelling\ expenditure} \times \boldsymbol{unit\ conversion\ factor} \quad \text{(Equation 3)}$$

Example 3: Converting units for gas heating in residential buildings

Expenditure in gas heating units	=	225	×	1	=	225

Description:	Opex for gas heating	Device to dwelling conversion factor	Opex for gas heating in NYCI unit
Unit:	$/device/year	Dwelling/device	$/dwelling/year

This is the final modelling step and $Expenditure\ in\ NYCI\ modelling\ unit$ is the final input format required by the NYCI modelling.

3. Mapping of PIA technology taxonomy to NYCI modelling taxonomy

Table 1 contains the mapping between PIA technology categories and NYCI modelling technology categories.

To simplify the NYCI modelling, 60 PIA technology categories will be excluded from the analysis for one of the following reasons:

1. The technology category represents negligible emissions and is sufficiently similar to the average profile of technologies in that subsector
2. No emissions in PIA for that technology category
3. The technology is not available in the NYCI modelling
4. Miscellaneous subsectors which contribute negligibly to emissions in New York State to be treated exogenously

Note that similar to the PIA approach, the electricity sector emissions will be treated as a distinct sector where relevant. Therefore, end uses that are primarily electricity are not themselves represented in the model.

The excluded technology categories represent a very small share of the total technology mix, which is then redistributed proportionally amongst the remaining technology categories. Excluded categories make up less than 2% of their respective subsectors.

The activity of remaining categories within the same subsector is scaled up proportionally to ensure that the total activity for each subsector is aligned between the PIA and NYCI modelling. This redistribution and scaling process is illustrated in Equation 4 for the case of a transportation technology; similar scaling is undertaken for other sectors with appropriate usage metrics. The exceptions to this rule are those PIA technology categories in miscellaneous subsectors excluded for reason #4. These subsectors are grouped in the 'other' category in NYCI modelling and treated as exogenous instead.

$$\textit{Scaled included technology VMT}^{5} = \textit{Unscaled included technology VMT} \times \frac{\textit{Total sector VMT}}{\textit{Total excluded technology VMT}} \quad \text{(Equation 4)}$$

[5] VMT – vehicle miles travelled

Table 1. Mapping of PIA technology categories to NYCI modelling technology categories

Transportation

Rationale for exclusion:
1. Negligible emissions, similar to subsector average technologies profile
2. No emissions in PIA
3. Technology not available in NYCI modelling
4. Contribute negligibly to emissions, treated exogenously

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Light Duty Vehicles - Cars	Gasoline	Passenger cars	ICE	
Light Duty Vehicles - Cars	Diesel	Passenger cars	ICE	
Light Duty Vehicles - Cars	CNG	Passenger cars	CNG	
Light Duty Vehicles - Cars	Plug in Hybrid Electric	Passenger cars	PHEV	
Light Duty Vehicles - Cars	Battery Electric	Passenger cars	BEV	
Light Duty Vehicles - Cars	Hydrogen Fuel Cell	Passenger cars	FCEV	
Light Duty Vehicles - Trucks	Gasoline	Regional Light Trucks	ICE Regional Light Trucks	
Light Duty Vehicles - Trucks	Diesel	Regional Light Trucks	ICE Regional Light Trucks	
Light Duty Vehicles - Trucks	CNG			1 (0.004% of subsector VMT)
Light Duty Vehicles - Trucks	Plug in Hybrid Electric			1 (1.7% of subsector VMT)
Light Duty Vehicles - Trucks	Battery Electric	Regional Light Trucks	BEV Regional Light Trucks	
Light Duty Vehicles - Trucks	Hydrogen Fuel Cell	Regional Light Trucks	FC Regional Light Trucks	
Medium Duty Vehicles	Gasoline	Regional MDT	ICE Regional MDT	
Medium Duty Vehicles	Diesel	Regional MDT	ICE Regional MDT	
Medium Duty Vehicles	Diesel Electric Hybrid			1 (0% of subsector VMT
Medium Duty Vehicles	Battery Electric	Regional MDT	BEV Regional MDT	
Medium Duty Vehicles	CNG			1 (0.8% of subsector VMT)
Medium Duty Vehicles	Hydrogen Fuel Cell	Regional MDT	FC Regional MDT	
Heavy Duty Vehicles	Gasoline	Regional HDT	Heavy Duty Regional Diesel	
Heavy Duty Vehicles	Diesel	Regional HDT	Heavy Duty Regional Diesel	
Heavy Duty Vehicles	Diesel Electric Hybrid			1 (0% of subsector VMT)
Heavy Duty Vehicles	Hydrogen Fuel Cell	Regional HDT	Heavy Duty Regional Hydrogen	
Heavy Duty Vehicles	CNG			1 (0.3% of subsector VMT)
Heavy Duty Vehicles	Battery Electric	Regional HDT	Heavy Duty Regional BEV	
Buses	Gasoline	Buses	ICE Buses	
Buses	Diesel	Buses	ICE Buses	
Buses	CNG	Buses	CNG Buses	
Buses	Battery Electric	Buses	BEV Buses	

Residential

Rationale for exclusion:
1. Negligible emissions, similar to subsector average technologies profile
2. No emissions in PIA
3. Technology not available in NYCI modelling
4. Contribute negligibly to emissions, treated exogenously

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Building Shell - Large Multi Family	Basic Shell	Included in Space Heating	Included in Space Heating	
Building Shell - Large Multi Family	Deep Shell			
Building Shell - Large Multi Family	Reference Shell			
Building Shell - Single Family	Basic Shell			
Building Shell - Single Family	Deep Shell			
Building Shell - Single Family	Reference Shell			
Building Shell - Small Multi Family	Basic Shell			
Building Shell - Small Multi Family	Deep Shell			
Building Shell - Small Multi Family	Reference Shell			
Air Conditioning - Central	Air Source Heat Pump			4
Air Conditioning - Central	Central AC			4
Air Conditioning - Central	Efficient Central AC			4
Air Conditioning - Central	Gas Heat Pump			4
Air Conditioning - Central	Ground Source Heat Pump			4
Air Conditioning - Room	Room AC			4
Air Conditioning - Room	Efficient Room AC			4
Clothes Drying	Efficient Electric			4
Clothes Drying	Efficient Gas			4
Clothes Drying	Electric			4
Clothes Drying	Gas			4
Clothes Washing	Efficient Electric			4
Clothes Washing	Electric			4
Cooking	Efficient Gas Stove	Residential cooking	Gas stove	
Cooking	Electric Resistance Stove	Residential cooking	Electric stove	
Cooking	Induction Stove	Residential cooking	Electric stove	
Cooking	LPG Stove	Residential cooking	Gas stove	
Cooking	Reference Gas Stove	Residential cooking	Gas stove	
Dishwashing	Efficient Electric			4
Dishwashing	Electric			4
Exterior Lighting	CFL Exterior			4
Exterior Lighting	Halogen Exterior			4
Exterior Lighting	Incandescent Exterior			4
Exterior Lighting	LED Exterior			4
Freezing	Efficient Electric			4
Freezing	Electric			4
General Service Lighting	CFL GSL			4
General Service Lighting	Incandescent GSL			4
General Service Lighting	LED GSL			4
Linear Fluorescent Lighting	LED Linear Fluorescent			4
Linear Fluorescent Lighting	T08 Linear Fluorescent			4
Linear Fluorescent Lighting	T12 Linear Fluorescent			4

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Space Heating - Single Family	Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Single Family	Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Single Family	Air Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Single Family	Efficient Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Single Family	Efficient Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Single Family	Efficient Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Single Family	Efficient Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Single Family	Electric Resistance	Residential space heating	Electric + Basic Shell	
Space Heating - Single Family	Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Single Family	Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Single Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	Ground Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Single Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	LPG Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Single Family	Wood Stoves	Residential space heating	Wood + Basic Shell	
Space Heating - Small Multi Family	Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Small Multi Family	Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Small Multi Family	Air Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Small Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Small Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Small Multi Family	Efficient Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Small Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Small Multi Family	Electric Resistance	Residential space heating	Electric + Basic Shell	
Space Heating - Small Multi Family	Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Small Multi Family	Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Small Multi Family	Hybrid Oil Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Small Multi Family	Hybrid Gas Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	LPG Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Small Multi Family	Wood Stoves	Residential space heating	Wood + Basic Shell	
Space Heating - Large Multi Family	Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Large Multi Family	Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Large Multi Family	Air Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Large Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Basic Shell	
Space Heating - Large Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Basic Shell	
Space Heating - Large Multi Family	Efficient Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Large Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Large Multi Family	Electric Resistance	Residential space heating	Electric + Basic Shell	
Space Heating - Large Multi Family	Gas Heating	Residential space heating	Gas + Basic Shell	
Space Heating - Large Multi Family	Gas Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Large Multi Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Basic Shell	
Space Heating - Large Multi Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	LPG Furnace	Residential space heating	Gas + Basic Shell	
Space Heating - Large Multi Family	Wood Stoves	Residential space heating	Wood + Basic Shell	
Space Heating - Single Family	Distillate Boiler	Residential space heating	Oil + Reference Shell	

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Space Heating - Single Family	Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Single Family	Air Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Single Family	Efficient Distillate Boiler	Residential space heating	Oil + Reference Shell	
Space Heating - Single Family	Efficient Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Single Family	Efficient Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Single Family	Efficient Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Single Family	Electric Resistance	Residential space heating	Electric + Reference Shell	
Space Heating - Single Family	Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Single Family	Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Single Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	Ground Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Single Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	LPG Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Single Family	Wood Stoves	Residential space heating	Wood + Reference Shell	
Space Heating - Small Multi Family	Distillate Boiler	Residential space heating	Oil + Reference Shell	
Space Heating - Small Multi Family	Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Small Multi Family	Air Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Small Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Reference Shell	
Space Heating - Small Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Small Multi Family	Efficient Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Small Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Small Multi Family	Electric Resistance	Residential space heating	Electric + Reference Shell	
Space Heating - Small Multi Family	Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Small Multi Family	Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Small Multi Family	Hybrid Oil Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Small Multi Family	Hybrid Gas Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	LPG Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Small Multi Family	Wood Stoves	Residential space heating	Wood + Reference Shell	
Space Heating - Large Multi Family	Distillate Boiler	Residential space heating	Oil + Reference Shell	
Space Heating - Large Multi Family	Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Large Multi Family	Air Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Large Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Reference Shell	
Space Heating - Large Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Reference Shell	
Space Heating - Large Multi Family	Efficient Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Large Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Large Multi Family	Electric Resistance	Residential space heating	Electric + Reference Shell	
Space Heating - Large Multi Family	Gas Heating	Residential space heating	Gas + Reference Shell	
Space Heating - Large Multi Family	Gas Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Large Multi Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Reference Shell	
Space Heating - Large Multi Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	LPG Furnace	Residential space heating	Gas + Reference Shell	
Space Heating - Large Multi Family	Wood Stoves	Residential space heating	Wood + Reference Shell	
Space Heating - Single Family	Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Single Family	Distillate Furnace	Residential space heating	Oil + Deep Shell	

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Space Heating - Single Family	Air Source Heat Pump	Residential space heating	Heat pump + Deep Shell	
Space Heating - Single Family	Efficient Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Single Family	Efficient Distillate Furnace	Residential space heating	Oil + Deep Shell	
Space Heating - Single Family	Efficient Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Single Family	Efficient Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Single Family	Electric Resistance	Residential space heating	Electric + Deep Shell	
Space Heating - Single Family	Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Single Family	Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Single Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	Ground Source Heat Pump	Residential space heating	Heat pump + Deep Shell	
Space Heating - Single Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Single Family	LPG Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Single Family	Wood Stoves	Residential space heating	Wood + Deep Shell	
Space Heating - Small Multi Family	Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Small Multi Family	Distillate Furnace	Residential space heating	Oil + Deep Shell	
Space Heating - Small Multi Family	Air Source Heat Pump	Residential space heating	Heat pump + Deep Shell	
Space Heating - Small Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Small Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Deep Shell	
Space Heating - Small Multi Family	Efficient Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Small Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Small Multi Family	Electric Resistance	Residential space heating	Electric + Deep Shell	
Space Heating - Small Multi Family	Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Small Multi Family	Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Small Multi Family	Hybrid Oil Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Deep Shell	
Space Heating - Small Multi Family	Hybrid Gas Electric Heat Pump			2 (0.06% of subsector devices)
Space Heating - Small Multi Family	LPG Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Small Multi Family	Wood Stoves	Residential space heating	Wood + Deep Shell	
Space Heating - Large Multi Family	Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Large Multi Family	Distillate Furnace	Residential space heating	Oil + Deep Shell	
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Space Heating - Large Multi Family	Efficient Distillate Boiler	Residential space heating	Oil + Deep Shell	
Space Heating - Large Multi Family	Efficient Distillate Furnace	Residential space heating	Oil + Deep Shell	
Space Heating - Large Multi Family	Efficient Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Large Multi Family	Efficient Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Large Multi Family	Electric Resistance	Residential space heating	Electric + Deep Shell	
Space Heating - Large Multi Family	Gas Heating	Residential space heating	Gas + Deep Shell	
Space Heating - Large Multi Family	Gas Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Large Multi Family	Hybrid Oil Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	Ground Source Heat Pump	Residential space heating	Heat pump + Deep Shell	
Space Heating - Large Multi Family	Hybrid Gas Electric Heat Pump			2 (0.05% of subsector devices)
Space Heating - Large Multi Family	LPG Furnace	Residential space heating	Gas + Deep Shell	
Space Heating - Large Multi Family	Wood Stoves	Residential space heating	Wood + Deep Shell	
Reflector Lighting	CFL Reflector			4
Reflector Lighting	Halogen Reflector			4
Reflector Lighting	Incandescent Reflector			4

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Reflector Lighting	LED Reflector			4
Refrigeration	Efficient Electric			4
Refrigeration	Electric			4
Water Heating	Distillate Storage	Residential water heating	Oil Residential Water Heating	
Water Heating	Efficient Gas Instant	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	Efficient Gas Storage	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	Electric Heat Pump Storage	Residential water heating	Heat Pump Residential Water Heating	
Water Heating	Electric Resistance Storage	Residential water heating	Electric Residential Water Heating	
Water Heating	Gas Heat Pump Storage	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	Gas Instant	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	Gas Storage	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	LPG Storage	Residential water heating	Natural Gas Residential Water Heating	
Water Heating	Solar			3 (0% of subsector devices)

Commercial

Rationale for exclusion:

1. Negligible emissions, similar to subsector average technologies profile
2. No emissions in PIA
3. Technology not available in NYCI modelling
4. Contribute negligibly to emissions, treated exogenously

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Air Conditioning	Efficient Centrifugal Chiller	Commercial space cooling	High Efficiency Commercial Space Cooling	
Air Conditioning	Efficient Commercial Air Source Heat Pump	Commercial space cooling	Heat Pumps for Commercial Space Cooling	
Air Conditioning	Efficient Commercial Central AC	Commercial space cooling	High Efficiency Commercial Space Cooling	
Air Conditioning	Efficient Commercial Ground Source Heat Pump	Commercial space cooling	Heat Pumps for Commercial Space Cooling	
Air Conditioning	Efficient Reciprocating Chiller	Commercial space cooling	High Efficiency Commercial Space Cooling	
Air Conditioning	Efficient Rooftop AC	Commercial space cooling	High Efficiency Commercial Space Cooling	
Air Conditioning	Efficient WallRoom AC	Commercial space cooling	High Efficiency Commercial Space Cooling	
Air Conditioning	Reference Centrifugal Chiller	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Commercial Air Source Heat Pump	Commercial space cooling	Heat Pumps for Commercial Space Cooling	
Air Conditioning	Reference Commercial Central AC	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Commercial Gas Absorption Chiller	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Commercial Gas Heat Pump	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Commercial Ground Source Heat Pump	Commercial space cooling	Heat Pumps for Commercial Space Cooling	
Air Conditioning	Reference GasDriven AC	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Reciprocating Chiller	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference Rooftop Air Conditioner	Commercial space cooling	Conventional Commercial Space Cooling	
Air Conditioning	Reference WallRoom AC	Commercial space cooling	Conventional Commercial Space Cooling	
Building Shell	Basic Shell	Included in Space Heating	Included in Space Heating	
Building Shell	Deep Shell			
Building Shell	Reference Shell			
Cooking	Electric Induction Stove	Commercial cooking	Electric stove	
Cooking	Electric Resistance Stove	Commercial cooking	Electric stove	
Cooking	Gas Convection Oven	Commercial cooking	Gas stove	
Cooking	Gas Stove	Commercial cooking	Gas stove	

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
General Service Lighting	CFLs			4
General Service Lighting	Efficient Halogen			4
General Service Lighting	Halogen Edison ALine Lamp			4
General Service Lighting	Halogen Par38			4
General Service Lighting	Incandescent			4
General Service Lighting	LEDs			4
High Intensity Discharge Lighting	HighPressure Sodium			4
High Intensity Discharge Lighting	LED Substitute			4
High Intensity Discharge Lighting	Mercury Vapor			4
High Intensity Discharge Lighting	Metal Halide			4
Linear Fluorescent Lighting	Efficient Linear			4
Linear Fluorescent Lighting	LED Linear			4
Linear Fluorescent Lighting	Reference Linear			4
Refrigeration	Efficient Beverage Merchandisers			4
Refrigeration	Efficient Compressor Rack Systems			4
Refrigeration	Efficient Condensers			4
Refrigeration	Efficient Ice Machines			4
Refrigeration	Efficient ReachIn Freezers			4
Refrigeration	Efficient ReachIn Refrigerators			4
Refrigeration	Efficient Refrigerated Vending Machines			4
Refrigeration	Efficient Supermarket Display Cases			4
Refrigeration	Efficient WalkIn Freezers			4
Refrigeration	Efficient WalkIn Refrigerators			4
Refrigeration	Reference Beverage Merchandisers			4
Refrigeration	Reference Compressor Rack Systems			4
Refrigeration	Reference Condensers			4
Refrigeration	Reference Ice Machines			4
Refrigeration	Reference ReachIn Freezers			4
Refrigeration	Reference ReachIn Refrigerators			4
Refrigeration	Reference Refrigerated Vending Machines			4
Refrigeration	Reference Supermarket Display Cases			4
Refrigeration	Reference WalkIn Freezers			4
Refrigeration	Reference WalkIn Refrigerators			4
Space Heating	Air Source Heat Pump	Commercial space heating	Heat pump + Basic Shell	
Space Heating	Distillate Boiler	Commercial space heating	Oil + Basic Shell	
Space Heating	Distillate Furnace	Commercial space heating	Oil + Basic Shell	
Space Heating	Efficient Distillate Boiler	Commercial space heating	Oil + Basic Shell	
Space Heating	Efficient Gas Heating	Commercial space heating	Gas + Basic Shell	
Space Heating	Efficient Gas Furnace	Commercial space heating	Gas + Basic Shell	
Space Heating	Electric Boiler	Commercial space heating	Electric + Basic Shell	
Space Heating	Electric Resistance	Commercial space heating	Electric + Basic Shell	
Space Heating	Gas Heating	Commercial space heating	Gas + Basic Shell	
Space Heating	Gas Furnace	Commercial space heating	Gas + Basic Shell	
Space Heating	Hybrid Oil Electric Heat Pump			2 (0.07% of subsector devices)
Space Heating	Ground Source Heat Pump	Commercial space heating	Heat pump + Basic Shell	
Space Heating	Hybrid Gas Electric Heat Pump			2 (0.07% of subsector devices)

Pathways Integration Analysis		NYCI model		Rationale for exclusion
Subsector	**Technology**	**Subsector**	**Technology**	
Space Heating	Air Source Heat Pump	Commercial space heating	Heat pump + Deep Shell	
Space Heating	Distillate Boiler	Commercial space heating	Oil + Deep Shell	
Space Heating	Distillate Furnace	Commercial space heating	Oil + Deep Shell	
Space Heating	Efficient Distillate Boiler	Commercial space heating	Oil + Deep Shell	
Space Heating	Efficient Gas Heating	Commercial space heating	Gas + Deep Shell	
Space Heating	Efficient Gas Furnace	Commercial space heating	Gas + Deep Shell	
Space Heating	Electric Boiler	Commercial space heating	Electric + Deep Shell	
Space Heating	Electric Resistance	Commercial space heating	Electric + Deep Shell	
Space Heating	Gas Heating	Commercial space heating	Gas + Deep Shell	
Space Heating	Gas Furnace	Commercial space heating	Gas + Deep Shell	
Space Heating	Hybrid Oil Electric Heat Pump			2 (0.07% of subsector devices)
Space Heating	Ground Source Heat Pump	Commercial space heating	Heat pump + Deep Shell	
Space Heating	Hybrid Gas Electric Heat Pump			2 (0.07% of subsector devices)
Space Heating	Air Source Heat Pump	Commercial space heating	Heat pump + Reference Shell	
Space Heating	Distillate Boiler	Commercial space heating	Oil + Reference Shell	
Space Heating	Distillate Furnace	Commercial space heating	Oil + Reference Shell	
Space Heating	Efficient Distillate Boiler	Commercial space heating	Oil + Reference Shell	
Space Heating	Efficient Gas Heating	Commercial space heating	Gas + Reference Shell	
Space Heating	Efficient Gas Furnace	Commercial space heating	Gas + Reference Shell	
Space Heating	Electric Boiler	Commercial space heating	Electric + Reference Shell	
Space Heating	Electric Resistance	Commercial space heating	Electric + Reference Shell	
Space Heating	Gas Heating	Commercial space heating	Gas + Reference Shell	
Space Heating	Gas Furnace	Commercial space heating	Gas + Reference Shell	
Space Heating	Hybrid Oil Electric Heat Pump			2 (0.07% of subsector devices)
Space Heating	Ground Source Heat Pump	Commercial space heating	Heat pump + Reference Shell	
Space Heating	Hybrid Gas Electric Heat Pump			2 (0.07% of subsector devices)
Ventilation	Constant Flow			4
Ventilation	Efficient Constant Flow			4
Ventilation	Efficient Variable Flow			4
Ventilation	Variable Flow			4
Water Heating	Efficient Gas	Commercial water heating	Natural Gas Commercial Water Heating	
Water Heating	Electric Heat Pump Storage	Commercial water heating	Heat Pump Commercial Water Heating	
Water Heating	Electric Resistance Storage	Commercial water heating	Electric Commercial Water Heating	
Water Heating	Gas Instant	Commercial water heating	Natural Gas Commercial Water Heating	
Water Heating	Gas Storage	Commercial water heating	Natural Gas Commercial Water Heating	
Water Heating	Oil Storage	Commercial water heating	Oil Commercial Water Heating	
Water Heating	Solar with Electric Backup	Commercial water heating	Electric Commercial Water Heating	

4. Renewable fuel supply assumptions used for NYCI modeling

NYCI market modeling includes a representation of blending renewable natural gas and renewable diesel into the conventional fossil fuel supply. This involves estimating the amount of renewable fuel being blended into pipeline natural gas and motor diesel respectively. The estimated blend rates for pipeline natural gas and motor diesel are then applied uniformly in the model for downstream fuel uses in buildings and transportation respectively.

The modeling approach draws on two key inputs to determine the renewable fuel supply used for blending:

- **Emission factors:** the assumed emissions factors (metric ton CO_2e per MMBtu) for renewable fuels are equivalent to those used in the PIA Scenario 2.[6]
- **Fuel supply curves:** The supply curves assumed for this analysis are equivalent to those assumed in the PIA Scenario 2,[7] with the following adjustments:
    - The supply curve in and after 2030 is moved back to 2035 to reflect a slower ramp up of the biofuels market
    - 2025 renewable fuel supplies are 10% of 2035 values with linear interpolation between these years
    - Relative to the PIA, more feedstock is used for renewable natural gas rather than renewable diesel.

The modeling approach estimates the fuel blending rate by assuming that fuel suppliers would acquire and blend renewable fuels available to New York State if they are cost-competitive against the conventional fossil fuel supply. Since the underlying emissions intensity of fossil fuels are higher than renewable fuels, a higher NYCI allowance price may enable a greater quantity of renewable fuels to become cost-competitive, and hence blended into the fuel mix. In other words, renewable fuels are blended up to the point where the marginal cost (adjusted for NYCI allowance price) of renewable fuels [RF] is equal to that of fossil fuels [FF], i.e., Equation 5:

$$\boldsymbol{FF\ cost + FF\ emissions\ factor \times NYCI\ allowance\ price} = \boldsymbol{RF\ cost + RF\ emissions\ factor \times NYCI\ allowance\ price} \quad \text{(Equation 5)}$$

The underlying cost of renewable fuel supply is governed by supply curves as shown in Exhibits 2 and 3. The supply curves indicate the relationship between the cost of fuel supply (in $ per MMBtu) and the supply quantities that are assumed to be available to New York State (in TBtu, or million MMBtu). As shown, renewable fuel supply is constrained due to cost of available feedstock and production sources. For renewable natural gas, supply becomes available to New York State when its price exceeds $22

[6] NYSERDA. 2022. *Integration Analysis Technical Supplement, Section I, Annex 1: Inputs and Assumptions, 'Emissions Factors'*. climate.ny.gov/resources/scoping-plan/

[7] NYSERDA. 2022. *Appendix G: Integration Analysis Technical Supplement New York State Climate Action Council Scoping Plan*, pp. 108. climate.ny.gov/resources/scoping-plan/

per MMBtu. Similarly, for renewable diesel, supply becomes available when its price exceeds $38 per MMBtu.

Exhibit 2. Supply curve for renewable natural gas

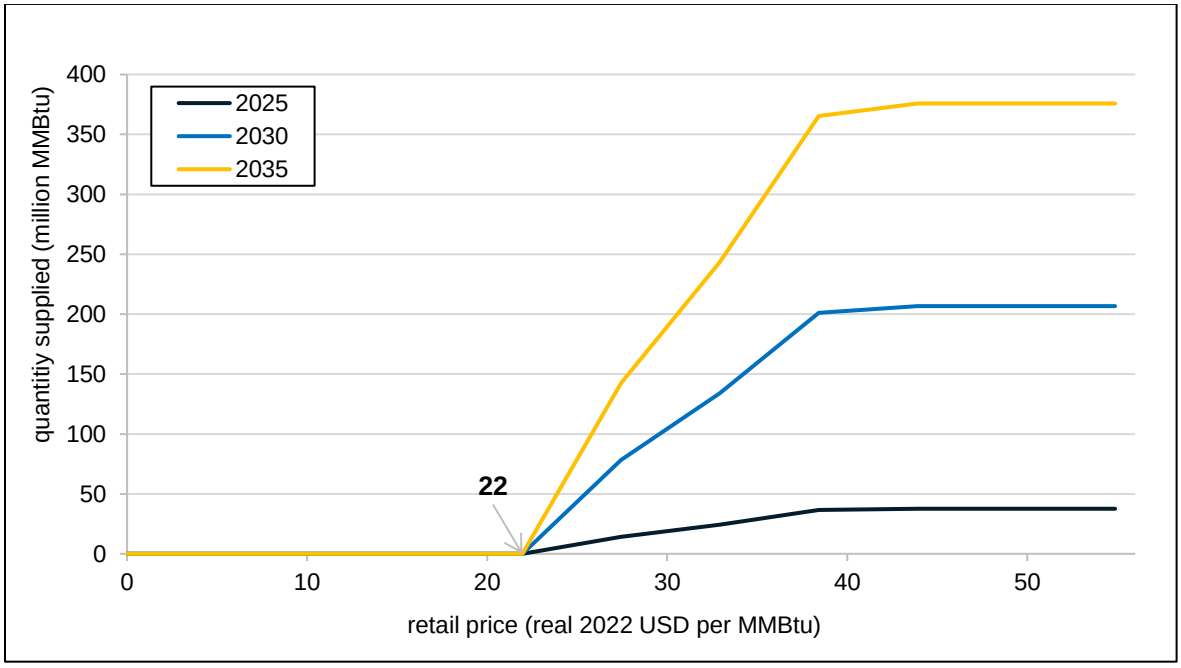

Exhibit 3. Supply curve for renewable diesel