CENTRAL GAS SITE PLAN

SP# 08-23

STAFF REPORT

May 29, 2024

(See January 24, 2024 & February 28, 2024 Meeting Materials)

SITE: 77 Central Street, Map 182 / Lot 217

ZONING: Business (B)

PURPOSE OF PLAN: To depict the proposed layout for a gas station and convenience store with drive-through window and all associated site improvements.

PLAN UNDER REVIEW:

Central Gas Site Plan, Non-Residential Site Plan, Map 182 Lot 217, 77 Central Street, Hudson, NH; prepared by: Keach-Nordstrom Associates, Inc. 10 Commerce Park North, Suite 3, Bedford, NH 03110; prepared for: Nottingham Square Corporation, 46 Lowell Road, Hudson, NH, 03051; consisting of 20 sheets and general notes 1-39 on Sheet 1; dated July 10, 2023; last revised May 9, 2024.

ATTACHMENTS:
1) Project Application and Associated Waiver Requests, prepared by Fuss & O'Neill, November 1, 2023 – Attachment "**A**"
2) Noise Study, prepared by Acentech incorporated, dated April 22, 2024 – Attachment "**B**"
3) Applicant Response to Planning Board Member comments, prepared by Keach-Nordstrom Associates, Inc., received May 13, 2024 – Attachment "**C**"
4) Similar Gas Station Project examples & photos, prepared by Keach-Nordstrom Associates, Inc., received May 13, 2024 – Attachment "**D**"
5) CAP Fee worksheet – Attachment "**E**"
6) Public Comments received since last meeting "**F**"

APPLICATION TRACKING:
- August 16, 2022 – Conceptual plan received.
- September 14, 2022 – Design Review meeting held.
- July 10, 2023 – Site plan application received.
- November 29, 2023 – Hearing continued to December 27.
- December 27, 2023 – Public hearing scheduled, Deferred to January 24.
- January 24, 2024 – Public hearing scheduled, continued to February 28, 2024.
- February 28, 2024 – Public hearing scheduled, continued to May 8, 2024.
- May 8, 2024 – Public hearing scheduled, deferred to May 29, 2024.
- May 29, 2024 – Public hearing scheduled.

COMMENTS & RECOMMENDATIONS:

BACKGROUND

The site is approximately 2.9 acres and is located in the Business zone. The proposed site is currently five parcels. Map 182 Lots: 216, 217, 218-1, 218-2, and 219, which the applicant wishes to consolidate. Five buildings totaling 6,321 SF were on the site that were previously used as single-family residential homes, but have since been razed. The site is served by municipal water and sewer. A small section on the southern end of the site is within the "A" or 100-year flood zone. There is a wetland on the southeast and southern edges of the site, along Map 190 Lots 185 and 186.

The applicant proposes building a 10-pump gas station with a 4,560 SF convenience store with drive-thru window. The Applicant has submitted a waiver request from the 100-foot buffer between commercial and residential uses required under §276-11.1(12)(c). The improvements that fall within this buffer are:

- the driveway curb cuts on Central Street and Lowell Road and,
- both proposed locations of the freestanding signs.

The site is proposed be accessed by two drives, a 20' wide one-way entrance driveway to be constructed on Lowell road approximately 210' from the intersection of Lowell Road and Central Street, and a 24.1' wide two-way entrance on Central Street, approximately 600' from the intersection of Central Street and Lowell Road. The proposal of two driveways requires a waiver from §193-10.G, for which a waiver request has been submitted. Further discussion below with Attachment "**D**".

The Applicant previously presented this plan to the Planning Board under Design Review Phase in September 2022. In response to the feedback heard during that phase, the Applicant has included architectural renderings with this application.

NOISE STUDY

As part of materials submitted on May 14, 2024, the applicant has provided a noise study per the Planning Board's request, prepared by Acentech Incorporated. (Attachment "**B**") The study covers all normal/predictable noises to be generated by a gas station, and found that even in the unlikely circumstance of all noises sources operating simultaneously (i.e., all 10 pumps actively in use whilst customers are being serviced in the drive-thru) the site is not projected to exceed continuous sound-level limits as outlined by **§249-4 – Prohibited noise emissions and conditions**, let alone impulsive sound-level limits. This is in line with expectations for the site, as gas stations are not particularly noisy or subject to stochastic spikes in sound-levels.

PLANNING BOARD QUESTIONS

The applicant has provided a detailed list of answers to questions posed by Mr. Crowley in Attachment "**C**". Several notes have been added to the plans in line with meeting requests laid out in the attachment. No areas of substantial concern were discovered as part of the questions. To corroborate points made in relation to site design and the need for two driveways, the applicant has provided details and photos over numerable gas station sites that also feature two curb cuts. Example sites and photography may be found in Attachment "**D**".

WAIVERS REQUESTED

As noted above, the Applicant is seeking two waivers:

1. Waiver for Buffer between Commercial and Residential Uses, **§276-11.1B(12)(C)**, to not require a 100' buffer between commercial and residential uses. The Applicant states that due to the layout of the site, not granting a waiver would make the land virtually undevelopable for any non-residential uses.

2. Waiver for Driveway Design Criteria, **§193-10.G**, to allow for more than one driveway onto the proposed site. The Applicant states that denial would result in the site being less desirable for future customers, suppliers, and vendors, while also forcing traffic from Lowell Road through and already busy intersection to access the site, in addition to limiting access for responding emergency vehicles.

RECOMMENDATIONS

Staff recommends discussion of questions or additional information the Planning Board may seek, followed by deliberation and consideration of waiver requests and approval. Staff believe that the applicant has provided more than adequate information for the board to make an informed decision on the project.

DRAFT MOTIONS:

WAIVER MOTIONS:

1. I move to grant a waiver from **§ 276-11.1.B(12)(C)**, General Plan Requirements, to not require a 100' buffer between commercial and residential uses, based on the Board's discussion, the testimony of the Applicant's representative, and in accordance with the language included in the submitted Waiver Request Form for said waiver.

Motion by: ___________________Second: ____________________Carried/Failed: _____________

2. I move to grant a waiver from **§ 193-10.G**, Driveway Design Criteria, to allow for more than one driveway onto the proposed site, based on the Board's discussion, the testimony of the Applicant's representative, and in accordance with the language included in the submitted Waiver Request Form for said waiver.

Motion by: ___________________Second: ____________________Carried/Failed: _____________

MOTION TO CONTINUE:

I move to continue the site plan application for Central Gas Site Plan SP# 08-23, 77 Central Street, Hudson, NH / Non-Residential Site Plan, Map 182 / Lot 217, to date certain, ___________, 2024.

Motion by: ___________________Second: ____________________Carried/Failed: _____________

MOTION TO APPROVE:

I move to approve the site plan application for the Site Plan entitled: Central Gas Site Plan, Non-Residential Site Plan, Map 182 Lot 217, 77 Central Street, Hudson, NH; prepared by: Keach-Nordstrom Associates, Inc. 10 Commerce Park North, Suite 3, Bedford, NH 03110; prepared for: Nottingham Square Corporation, 46 Lowell Road, Hudson, NH, 03051; consisting of 20 sheets and general notes 1-39 on Sheet 1; dated July 10, 2023; last revised May 9, 2024; and:

That the Planning Board finds that this application complies with the Zoning Ordinances, and with the Land Use Regulations with consideration of the waivers granted; and for the reasons set forth in the written submissions, together with the testimony and factual representations made by the applicant during the public hearing;

Subject to, and revised per, the following stipulations:

1. All stipulations of approval shall be incorporated into the Development Agreement, which shall be recorded at the HCRD, together with the Site Plan-of-Record and all agreed upon easement deeds, which shall be favorable reviewed by Town Counsel prior to Planning Board endorsement of the Plan.
2. A cost allocation procedure (CAP) amount of $51,488.00 shall be paid prior to the issuance of a Certificate of Occupancy.
3. Prior to the issuance of a final certificate of occupancy, an L.L.S. Certified "As-Built" site plan shall be provided to the Town of Hudson Land Use Department, confirming that the site conforms to the Planning Board approved Site Plan.
4. Prior to the Planning Board endorsement of the Plan, it shall be subject to final administrative review by Town Planner and Town Engineer.
5. Prior to application for a building permit, the Applicant shall schedule a pre-construction meeting with the Town Engineer.
6. Maintenance of the onsite drainage system shall be constructed and maintained in compliance with NHDES requirements for such systems.
7. Construction activities involving the subject lot shall be limited to the hours between 7:00 A.M. and 7:00 P.M., Monday through Saturday. No exterior construction activities shall be allowed on Sundays.
8. Hours of refuse removal shall be exclusive to the hours between 7:00 A.M. and 7:00 P.M., Monday through Friday only.
9. Prior to the issuance of a final certificate of occupancy, a Spill Prevention Plan shall be provided to, and approved by, the Fire Marshall.

Motion by: ____________________ Second: ____________________ Carried/Failed: ____________

LOT MERGER APPLICATION FOR TAX ASSESSMENT AND LAND USE PURPOSES

TOWN OF HUDSON, NEW HAMPSHIRE

The undersigned, Manuel Sousa - Nottingham Square Corporation (type or print name here) is / are the owner(s) of lots or parcels shown on the Town Tax Maps as follows:

Tax Map 182	Lot 216	Tax Map 182	Lot 218-2
Tax Map 182	Lot 217	Tax Map 182	Lot 219
Tax Map 182	Lot 218-1		

The undersigned requests that the Town of Hudson Planning Board combine the above described parcels or lots into one parcel or one lot to be known as, Tax Map 182, Lot 217 for tax assessment, and land use purposes.

The undersigned acknowledges and agrees that the merged lots or parcels shall be shown as a single lot or single parcel on the Town Tax map and shall be one lot or one parcel for land use purposes. The Town of Hudson will assess the merged lots or merged parcels as a single lot or a single parcel.

If at any time the undersigned, or its heirs, legatees, successors and assigns of the undersigned wish to subdivide the merged lot or merged parcel, subdivision approval must be obtained from the Town of Hudson Planning Board under the Town of Hudson Subdivision of Land Regulations.

The undersigned agrees that the approval of this application shall be filed at the expense of the undersigned in the Hillsborough County Registry of Deeds.

Dated this 6 day of July, 2023.

Manuel D. Sousa (SIGN HERE) LANDOWNER | _______________ (SIGN HERE) LANDOWNER

_______________ (TYPE OR PRINT NAME) | _______________ (TYPE OR PRINT NAME)

This application for the merger of lots for tax assessment and land use purposes is approved by action of the Town of Hudson Planning Board. This application shall be recorded in the Hillsborough County Registry of Deeds.

Dated this _____ day of ________________, 20____.

_______________ (SIGN HERE)
CHAIRPERSON
HUDSON PLANNING BOARD

____
(TYPE OR PRINT NAME)

Town of Hudson
12 School Street
Hudson, NH 03501

SITE PLAN APPLICATION

Revised May 19, 2023

The following information must be filed with the Planning Department ***at the time of filing a site plan application***:

1. One (1) original completed application with original signatures, and one (1) copy.

2. Three (3) full plan sets (sheet size: 22" x 34").

3. One (1) original copy of the project narrative, and one (1) copy.

4. A list of direct abutters and a list of indirect abutters, and two (2) sets of mailing labels for abutter notifications.

5. All of the above application materials, including plans, shall also be submitted in electronic form as a PDF.

6. All plans shall be folded and all pertinent data shall be attached to the plans with an elastic band or other enclosure.

The following information is required to filed with the Planning Department ***no later than 10:00 A.M., Tuesday ONE WEEK prior to the scheduled Planning meeting. The purpose of these materials is hardcopy distribution to Planning Board members, not review. Any plan revisions that require staff review must be submitted no later than 10:00A.M., Tuesday TWO WEEKS prior to the scheduled Planning meeting. Depending on the complexity of changes, more time may be required for review. Please contact the Town Planner if you have any questions on this matter.***

1. Submission of fifteen (15) 11" X 17" plan sets, revised if applicable.

2. Submission of two (2) full plan sets (sheet size: 22" x 34"), if revised.

3. All of the above application materials, including plans, shall also be submitted in electronic form as a PDF.

Note: Prior to filing an application, it is recommended to schedule an appointment with the Town Planner.

SITE PLAN APPLICATION

Date of Application: July 10, 2023 Tax Map #: 182 Lot #: 217

Site Address: Lowell Road & Central Street

Name of Project: Central Gas

Zoning District: Business (B) General SP#: ______ (For Town Use Only)

Z.B.A. Action: ______

PROPERTY OWNER:	DEVELOPER:
Name: Nottingham Square Corporation	
Address: 46 Lowell Road	
Address: Hudson, NH 03051	
Telephone # 603-880-7799	
Email: msousa@sousarealtynh.com	

PROJECT ENGINEER:	SURVEYOR:
Name: Paul Chisholm, PE - KNA	Anthony Basso, LLS - KNA
Address: 10 Commerce Park North, Suite 3	10 Commerce Park North, Suite 3
Address: Bedford, NH 03110	Bedford, NH 03110
Telephone # 603-627-2881	603-627-2881
Email: pchisholm@keachnordstrom.com	abasso@keachnordstrom.com

PURPOSE OF PLAN:

The purpose of the plan is to depict the proposed layout for a gas station and convenience store with drive thru window and all associated site improvements.

(For Town Use Only)

Routing Date: ______ Deadline Date: ______ Meeting Date: ______

______ I have no comments ______ I have comments (attach to form)

______ Title: ______ Date: ______
(Initials)

Department:

Zoning: ___ Engineering: ___ Assessor: ___ Police: ___Fire: ___ DPW: ___ Consultant: ___

SITE DATA SHEET

PLAN NAME: Central Gas

PLAN TYPE: SITE PLAN

LEGAL DESCRIPTION: MAP 182 LOT 217

DATE: July 10, 2023

Location by Street:	Lowell Road & Central Street
Zoning:	Business (B)
Proposed Land Use:	Gas Station/Convenience Store with Drive Thru
Existing Use:	Residential
Surrounding Land Use(s):	Commercial & Residential
Number of Lots Occupied:	One (1) - Following Lot Merger
Existing Area Covered by Building:	6,321 SF
Existing Buildings to be removed:	Five (5)
Proposed Area Covered by Building:	4,560 SF
Open Space Proposed:	62%
Open Space Required:	40%
Total Area:	S.F.: 126,607 Acres: 2.90
Area in Wetland:	2,881 SF Area Steep Slopes: 10,899 SF
Required Lot Size:	30,000 SF
Existing Frontage:	982.2 FT
Required Frontage:	150 FT

Building Setbacks:	Required*	Proposed
Front:	50 FT	72.7 FT
Side:	15 FT	N/A
Rear:	15 FT	331.6 FT

SITE DATA SHEET
(Continued)

Flood Zone Reference: 33011C0518D

Width of Driveways: 24 FT

Number of Curb Cuts: Two (2)

Proposed Parking Spaces: 41 Spaces

Required Parking Spaces: 41 Spaces

Basis of Required Parking (Use): Gas Pumps, Convenience Store, Drive Thru

Dates/Case #/Description/Stipulations of ZBA, Conservation Commission, NH Wetlands Board Actions:
(Attach stipulations on separate sheet)

Waiver Requests

Town Code Reference:	*Regulation Description:*
276-11.1(12)(c)	Drive Aisles within 100-ft Abutting Residential Property

(For Town Use Only)

Data Sheets Checked By: ______________________ Date: ____________

SITE PLAN APPLICATION AUTHORIZATION

I hereby apply for *Site Plan* Review and acknowledge I will comply with all of the Ordinances of the Town of Hudson, New Hampshire State Laws, as well as any stipulations of the Planning Board, in development and construction of this project. I understand that if any of the items listed under the *Site Plan* specifications or application form are incomplete, the application will be considered rejected.

Pursuant to RSA 674:1-IV, the owner(s) by the filing of this application as indicated above, hereby given permission for any member of the Hudson Planning Board, the Town Planner, the Town Engineer, and such agents or employees of the Town or other persons as the Planning Board may authorize, to enter upon the property which is the subject of this application at all reasonable times for the purpose of such examinations, surveys, tests and inspections as may be appropriate. The owner(s) release(s) any claim to or right he/she (they) may now or hereafter possess against any of the above individuals as a result of any examinations, surveys, tests and/or inspections conducted on his/her (their) property in connection with this applications.

Signature of Owner: [signature] Date: 7/6/23

Print Name of Owner: Manuel Sousa

- ❖ If other than an individual, indicate name of organization and its principal owner, partners, or corporate officers.

Signature of Developer: ____________________ Date: ________

Print Name of Developer: ____________________

- ❖ The developer/individual in charge must have control over all project work and be available to the Code Enforcement Officer/Building Inspector during the construction phase of the project. The individual in charge of the project must notify the Code Enforcement Officer/Building Inspector within two (2) working days of any change.

WAIVER REQUEST FORM

Name of Subdivision/Site Plan: Central Gas

Street Address: Lowell Road & Central Street

I Manuel Sousa hereby request that the Planning Board waive the requirements of item 276-11.1(12)(c) of the Hudson Land Use Regulations in reference to a plan presented by Keach-Nordstrom Associates, Inc. (name of surveyor and engineer) dated July 10, 2023 for property tax map(s) 182 and lot(s) 217 in the Town of Hudson, NH.

As the aforementioned applicant, I, herein, acknowledge that this waiver is requested in accordance with the provisions set forth in RSA 674:36, II (n), i.e., without the Planning Board granting said waiver, it would pose an unnecessary hardship upon me (the applicant), and the granting of this waiver would not be contrary to the spirit and intent of the Land Use Regulations.

Hardship reason(s) for granting this waiver (if additional space is needed please attach the appropriate documentation hereto):

See Attached Waiver Request

Reason(s) for granting this waiver, relative to not being contrary to the spirit and intent of the Land Use Regulations: (if additional space is needed please attach the appropriate documentation hereto):

See Attached Waiver Request

Signed: Katherine Cooper

Applicant or Authorized Agent

SCHEDULE OF FEES

A. REVIEW FEES:

1. Site Plan Use	Project Size/Fee	
Multi-Family	$105.00/unit for 3-50 units $78.50/unit for each additional unit over 50	$ -
Commercial/Semi Public/Civic or Recreational 4,560 SF	$157.00/1,000 sq. ft. for first 100,000 sq.ft. (bldg. area): $78.50/1,000 sq.ft. thereafter.	$ 715.92
Industrial	$150.00/1,000 sq.ft for first 100,000 sq.ft. (bldg. area); $78.50/1,000 sq.ft thereafter.	$ -
No Buildings	$30.00 per 1,000 sq.ft. of proposed developed area	$ -

CONSULTANT REVIEW FEE: (Separate Check)

Total 2.90 acres @ $600.00 per acre, or $1,250.00, whichever is greater. $ 1,740.00

This is an estimate for cost of consultant review. The fee is expected to cover the amount. A complex project may require additional funds. A simple project may result in a refund.

LEGAL FEE:

The applicant shall be charged attorney costs billed to the Town for the Town's attorney review of any application plan set documents.

B. POSTAGE:

17 Direct Abutters Applicant, Professionals, etc. as required by RSA 676:4.1.d @$4.78 (or Current Certified Mail Rate) $ 81.26

8 Indirect Abutters (property owners within 200 feet) @$0.63 (or Current First Class Rate) $ 5.04

C. TAX MAP UPDATING FEE: (FLAT FEE) $ 275.00

TOTAL $ 2,817.22

Check #1: $1,077.22 (Town)
Check #2: $1,740.00 (Review)

SCHEDULE OF FEES
(Continued)

(For Town Use)			
AMOUNT RECEIVED:	$________	DATE RECEIVED:	________
RECEIPT NO.:	________	RECEIVED BY:	________

NOTE: fees below apply only upon plan approval, not collected at time of application.

D. RECORDING:

*****The applicant shall be responsible for the recording of the approved plan, and all documents as required by an approval, at the Hillsborough County Registry of Deeds (HCRD), located at 19 Temple Street, Nashua, NH 03061. Additional fees associated with recording can be found at HCRD.*****

E. COST ALLOCATION PROCEDURE AMOUNT CONTRIBUTION AND OTHER IMPACT FEE PAYMENTS:

To be determined by the Planning Board at time of plan approval and shall be paid by the applicant at the time of submittal of the Certificate of Occupancy Permit requests.

*****The applicant shall be responsible for all fees incurred by the town for processing and review of the applicant's application, plan and related materials.*****

Attachment "A"

KNA KEACH-NORDSTROM ASSOCIATES, INC.

July 10, 2023

Town of Hudson
Planning Department
12 School Street
Hudson, New Hampshire 03051

Subject: **Non-Residential Site Plan – Central Gas**
Tax Map 182; Lot 217
Lowell Road & Central Street – Hudson, New Hampshire
KNA Project No. 18-0612-3

Project Narrative

The subject property, located at the corner of Lowell Road and Central Street, is referenced on Hudson Tax Map 182 as Lots 216, 217, 218-1, 218-2, and 219. These five (5) lots will be consolidated into a single parcel referenced as Tax Map 182 Lot 217 with a combined area of approximately 2.90 acres. The parcel is located entirely within the Business (B) Zoning District. It was developed with single family residential homes at the time of survey, but those have since been removed. The surrounding land uses include commercial, single family residential, and multi-family residential.

The applicant is proposing to construct a 10-pump gas station, a 4,560 square foot convenience store with drive thru window, and all associated site improvements. Access to the site will be provided via two (2) new 24-foot-wide driveways, one (1) on Lowell Road and one (1) on Central Street. The lot will be serviced by municipal water and sewer. Other site improvements include stormwater management provisions, paved parking areas, utility connections, landscaping, and lighting. No impacts to the wetlands or 50-ft wetland buffer are proposed.

KNA *KEACH-NORDSTROM ASSOCIATES, INC.*

July 10, 2023

Town of Hudson
Planning Department
12 School Street
Hudson, New Hampshire 03051

Subject: **Waiver Request – Central Gas**
Tax Map 182; Lot 217
Lowell Road & Central Street – Hudson, New Hampshire
KNA Project No. 18-0612-3

The Applicant is requesting a waiver from the following section of the Town of Hudson Site Plan Regulations: **Section 276-11.1(12)(c) 100-ft Buffer Between Commercial and Residential Uses**

Hardship reason(s) for granting this waiver:
Based on the location of the abutting residential uses, accessing the site would require a driveway to be located within the 100-ft buffer zone. By not allowing the Applicant to construct driveways, access to the property would be severely restricted making it virtually undevelopable for any non-residential use.

Reason(s) for granting this waiver, relative to not being contrary to the spirit and intent of the Land Use Regulations:
The spirit and intent of this regulation is to provide a 100-ft buffer between residential and non-residential uses. The majority of the developed areas fall outside this buffer zone, however, the entrance driveways to the site are located within the buffer which extends the full width of the Central Street frontage and a significant portion of the Lowell Road frontage. Based on the location of the abutting residential uses, any access driveway would be located within this buffer zone. The remainder of the site improvements do not need to be located within this buffer and are not proposed to be. Therefore, granting this waiver would not be contrary to the spirit and intent of the Town of Hudson Site Plan Regulations.

10 Commerce Park North, Suite 3B Bedford, NH 03110 Phone (603) 627-2881 Fax (603) 627-2915

Attachment "A"

KNA KEACH-NORDSTROM ASSOCIATES, INC.

September 18, 2023

Town of Hudson
Planning Department
12 School Street
Hudson, New Hampshire 03051

Subject: **Waiver Request – Central Gas**
Tax Map 182; Lot 217
Lowell Road & Central Street – Hudson, New Hampshire
KNA Project No. 18-0612-3

The Applicant is requesting a waiver from the following section of the Town of Hudson Site Plan Regulations: **Section 193.10.G. Driveway Design Criteria – Single Driveway Per Parcel**

Hardship reason(s) for granting this waiver:
The subject parcel is situated at a busy intersection on Lowell Road and Central Street. The project proposes two driveways to support the development, including a one-way entrance driveway on Lowell Road and a two-way driveway on Central Street. Allowing both driveways in this orientation will provide relief to the intersection by allowing vehicles turning right into the site from Lowell Road to avoid the intersection altogether. Granting this waiver will enhance site access and reduce traffic at the intersection. A denial would result in hardship because it would cause the site to be less desirable for future customers, suppliers and vendors while also forcing traffic from Lowell Road through an already busy intersection to access the site and limiting access for responding emergency vehicles.

Reason(s) for granting this waiver, relative to not being contrary to the spirit and intent of the Land Use Regulations:
The spirit and intent of the Land Use Regulations will not be opposed by granting this waiver. The intent of the driveway regulations is provide criteria for safe and adequate access to properties. The project proposes to consolidate multiple parcels. Three of the parcels at one time were occupied by houses and each had its own driveway access. As consolidated lots, the property would have adequate lot frontage on both Lowell Road and on Central Street. A turn in only driveway from Lowell Road would increase safety by allowing emergency vehicles a second means of access and quicker response time by not having to go through the busy intersection. One reason for limiting the amount of driveways per property helps reduce congestion to public streets. In this case, however, there will be less congestion by allowing a restricted turn in driveway from Lowell Road by allowing some travelers visiting the site from Lowell Road to avoid an intersection. Therefore, the spirit and intent of the regulation will be upheld by approving this waiver.

KNA KEACH-NORDSTROM ASSOCIATES, INC.

Attachment "B"

May 13, 2024

Town of Hudson
Planning Department
12 School Street
Hudson, New Hampshire 03051

Subject: **Non-Residential Site Plan – Central Gas**
Tax Map 182; Lot 217
Lowell Road & Central Street – Hudson, New Hampshire
KNA Project No. 18-0612-3

Dear Chairman and Board Members:

Supplemental materials and revised plans are being submitted for review and approval for the above referenced project. At the previous planning board hearing, the applicant was asked to obtain supplemental information regarding future noise generated from the project and its effect on the surrounding residential properties. As such, the applicant contracted Acentech Incorporated to complete a noise study for the property. Their findings are reported in the attached report.

The applicant was also asked to respond to two additional sets of comments from Planning Board member Mr. Crowley regarding the traffic study performed by VHB, and environmental concerns stemming from a separate site plan application in the project vicinity. Response letters to both sets of comments are included under this cover for review.

Lastly, the applicant feels it is beneficial to provide additional information regarding the requested driveway waiver and proposed site access points. The attached photos provide examples of five gas stations in and around Hudson, that currently operate similarly to the proposed project. Each existing site provides two points of access on separate roadways and shares characteristics with the current proposal (drive-thru with coffee shop, convenience store, open 24/7, etc). These specific examples are intended to demonstrate that the current waiver request is not only reasonable but commonplace for this type of application.

The attached documents outline the applicants request for approval. All required information has been included within the submittal package. Keach Nordstrom Associates, Inc. will be present to further discuss the Application at the scheduled hearing.

Enclosed is the following material for your review and approval:

1. Noise Study Prepared by Acentech Incorporated
2. Planning Board Response Letters
3. Similar Project Photos
4. One (1) Revised Full Size Plan Set
5. Fifteen (15) Revised Half Size Plan Set
6. Submittal in a PDF form

If you have any questions or comments, please contact me at (603) 627-2881.

Sincerely,

Peter Madsen, EIT
Project Engineer
Keach Nordstrom Associates
10 Commerce Park North, Suite 3
Bedford, NH 03110

Attachment "B"

ACENTECH
ACOUSTICS TECHNOLOGY VIBRATION

April 22, 2024

Many Sousa
Nottingham Square Corporation
46 Lowell Road
Hudson, NH 03051
c/o Peter Madsen; Keach-Nordstrom Associates, Inc.

Sent Via Email: pmadsen@keachnordstrom.com

Subject: Hudson Gas Station Community Noise Evaluation
Hudson, NH
Acentech Project Number: J637859

Dear Many & Peter,

Acentech is pleased to submit this letter report evaluating community (exterior) noise of the proposed gas station and convenience store (the Project) located at Central Street and Lowell Street in Hudson, New Hampshire. The Project will include 10 gas pumps and a 4,560 square foot convenience store with a drive-through window service and corresponding HVAC units.

A background noise survey was conducted onsite to establish the pre-construction ambient sound levels, as a basis for the project sound level limits. The equipment sound sources provided by your architects were entered into a sound model to determine if project noise levels at nearby residences would exceed the established limits. under all modeling conditions, the predicted future sound levels were below the limits as determined from the background sound survey and the Hudson noise ordinance.

SOUND LIMITS

TOWN OF HUDSON

The Town of Hudson has a noise ordinance under Section 249-4 of the Town Bylaws. This ordinance has 10 different noise limits (sub-sections A through J). The sub-sections that apply are: "Noise Limits" 2, 3, 4, 5 and 6. Noise Limit 2 and 4 will be the most relevant. Noise Limit 2 is for sounds that have a 1-hour duration, which would only apply to the mechanical equipment. Noise Limit 4 would apply to the speaker audio and requires that those items produce sound at the receiver no higher than 10 dB above existing sound levels. Additionally, section 249-4-E of the Hudson Noise Ordinance prohibits pure-tone conditions at nearby receptors, which occurs when the sound pressure level in one whole-octave band is 3 or more decibels higher than both of its adjacent octave bands.

STATE OF NEW HAMPSHIRE

The New Hampshire Department of Transportation (NHDOT) has noise limits that apply to highway projects. However, the State does not have general noise regulations which would apply to this project.

BACKGROUND SOUND SURVEY

A background sound survey was performed from April 3 to 10, 2024. Acentech deployed one sound level meter (SLM) at the location shown in Figure 1. We monitored sound continuously over a period of 7 days. During this period, we measured the A-weighted 90th percentile sound pressure level (L_{90}) on an hourly basis of 24 hours per day along with other metrics that can be reported as needed.

INSTRUMENTATION

We used Type 1 SLM in accordance with IEC 61672-1. The SLM was factory-calibrated to National Institute of Standards and Technology (NIST) traceable sources within the previous 12 months; the laboratory calibration certificates are available upon request. The SLM was also field calibrated before and after the start of the survey. The SLM was set to slow response, and recorded L_{90} sound pressure levels in one-hour increments in octave-bands with center frequencies between 31.5 and 8,000 Hz. The equivalent continuous (L_{EQ}) A-weighted sound level (dBA) and unweighted (dBZ) octave-band SPLs were also recorded.

SURVEY RESULTS

Figure 2 is a graph of the A-weighted sound levels for the entire 7-day period. We have compiled the L_{90} sound level and determined the lowest L_{90} sound level for the daytime and nighttime periods. The minimum, average and maximum hourly L_{90} sound levels for day and night are given in Table 1, where daytime hours occur between 7:00 AM and 6:00 PM nighttime hours occur between 6:00 PM and 7:00 AM.

TABLE 1: Summary of Background Sound Levels, dBA
(Overall Minimum Hourly L_{90} shown in Red)

Day	Date	Minimum Daytime	Minimum Nighttime
Wednesday	4/3/2024	55	45
Thursday	4/4/2024	52	43
Friday	4/5/2024	54	42
Saturday	4/6/2024	50	41
Sunday	4/7/2024	48	41
Monday	4/8/2024	51	41
Tuesday	4/9/2024	48	41
Wednesday	4/10/2024	50	40

PROJECT NOISE LIMIT

Based on the Town of Hudson ordinance noted above, we have defined a sound limit based on the existing background sound levels as given in Table 1. The minimum background sound (hourly L_{90}) occurred on Wednesday, April 10th at 1:00 am as shown with a red dot on Figure 2, at a value of 40 dBA. This means that future project noise cannot exceed a broadband sound level of 50 dBA at nearby residences.

NOISE COMPUTATIONS

Acentech developed an acoustic model of the proposed gas station, convenience store, and drive-through. The model has the ability to compute the sound levels from the various sound sources, and to determine the sound levels transmitted to the adjacent properties.

MODEL DESCRIPTION

The acoustic model was developed using the widely accepted software, Cadna/A, to estimate the contributions of various noise sources to the community sound levels. Cadna/A complies with international standard ISO 9613-2 "Attenuation of sound during propagation outdoors – Part 2: General method of calculation". Table 2 provides the modeled sound power levels (L_W) of the various proposed sound sources to be used at this site. These quantities are used in the model to predict the sound pressure levels at various locations. We have used measured sound levels from existing drive-through speakers and existing gas pump speakers. These measurements were conducted at various Dunkin Donuts drive-through locations and gas-pump speakers at set distances by Acentech staff. We have converted the measured sound pressure levels into sound power levels as given in Table 2. Given that the location of the two future Rooftop-units (RTU) is still to-be-determined, we conservatively assumed that two provided units were located as close as possible to nearby residences, which was on the southwest corner of the convenience store roof.

A default ground absorption factor of 0.5 was used, which represents a combination of hard reflective ground conditions indicative of the paved parking lots/streets, and soft ground conditions representative of the grassy areas at the Project. All receiver heights were set at 5 feet (1.5 m) with the exception of 78 Central Street and 76 Central Street, which were set at a height of 33 feet (10 m) and 21 feet (6.5 m) respectively, to represent the top story windows.

Terrain can have a significant impact on how outdoor noise interacts with its surroundings and how it transmits from the sound sources to the receiver locations. Ground elevation height contours using United States Geological Survey (USGS) were also imported into the sound model from the National Oceanic and Atmospheric Administration (NOAA) [1] data viewer.

TABLE 2: Modeled Source Sound Power Levels (Lw), dB re 1 pico-watt

Name	Quantity	Octave Band Center Frequency, Hz									
		31.5	63	125	250	500	1000	2000	4000	8000	dBA
Roof-top Unit[1]	2	94	91	88	85	82	79	76	73	80	85
Gas Pump Speaker	10	66	61	62	76	79	79	76	41	51	82
Drive-Through Speaker	1	64	64	54	65	72	74	72	53	47	77

[1] – Overall broadband sound power levels provided in as 85 dBA in RTU ZT090S18U2B5RAE1A2 specifications, octave band levels assumed

BASELINE RESULTS

We have defined twelve locations around the project where we have computed the sound levels. Modeling results were conducted under six different test conditions: 1 gas pump speaker on, 5 gas pump speakers on (50%), 10 gas pump speakers on (100%), drive-through window only, mechanical equipment only, and all sources on. The location of the twelve receptors are shown over aerial imagery in Figure 3.

BROADBAND A-WEIGHTED SOUND LEVELS

Table 3 presents the computed broadband A-weighted sound levels at the twelve receptor locations. All receptor locations along Center Street have sound levels at or above the minimum background sound level of 40 dBA as noted in Table 1. This table is sorted based on the 'worst case' condition with all sound sources on, sorted by overall sound level from high to low.

PURE TONE ANALYSIS

Section 249-4-E of the Hudson Noise Ordinance prohibits pure tones from project equipment at nearby receptors. A pure tone occurs when a whole octave the sound level at a particular octave band is 3 dB or more greater than each of the two adjacent bands. Table 2 shows that there were no pure tones in the source level sound data, and therefore pure tones would not be expected at nearby receptors. This was confirmed by the predicted octave band sound levels at the receiver locations, which are also calculated in the sound model. Tabular results of these octave band sound levels can be provided upon request. Pure tones can still occur if the modeled equipment and speaker octave band sound levels differ from the 'as installed' equipment and speaker sound levels.

[1] https://coast.noaa.gov/dataviewer/#/

TABLE 3: Computed Broadband A-weighted Sound Levels

Modeled Broadband Sound Levels at Nearby Receiver Locations						
Receiver Location	One Pump Speaker On	50% Pump Speakers On	100% Pump Speakers On	Drive-Through Window Only	Mechanical Equipment Only	All Sources On
	[dBA]	[dBA]	[dBA]	[dBA]	[dBA]	[dBA]
78 Central Street	38	44	47	23	38	46
76 Central Street	35	42	44	28	37	43
74 Central Street	33	39	42	23	35	41
11 Lowell Road	30	37	40	31	38	41
84 Central Street	27	36	38	31	39	41
9 Lowell Road	31	38	42	7	33	40
13 Lowell Road	30	37	40	28	37	40
15 Lowell Road	22	35	37	32	39	40
17 Lowell Road	22	33	36	29	38	39
20 Lowell Road	23	30	34	26	38	38
21 Lowell Road	24	31	34	27	37	38
3 Melendy Road	27	34	38	5	33	37

DISCUSSION

The provided sources will produce sound levels at nearby receiver locations that are all under the overall limit of 50 dBA at all nearby residential and business locations.

It is important to note that this study does not include sound sources from future gas station usage such as cars and trucks passing, pedestrian activity, and other sources. It is also important to note that since gas-pump speaker and drive-through speaker sound power levels were calculated from the measured sound levels of existing locations, it is possible that sound levels of the installed speakers could have different levels than the ones measured. This is also true for the mechanical equipment, as only the overall broadband sound power levels were provided, and the octave band sound levels were assumed.

Given the typical operation of the gas pumps, it is unlikely that all ten pump speakers will be running at once. Still, receiver sound levels would adhere to the Hudson noise ordinance under these conservative conditions. These sound analyses do not account for the sound impact of the customers for the proposed gas station/convenience store, which may include but are not limited to vehicular traffic around the facility, idle trucks and vehicles, and customer/employee conversations or activity.

Please contact us at 617-499-8058 or mBahtiarian@acentech.com with any questions or comments.

Sincerely,
ACENTECH INCORPORATED

Ethan Switzer
Consultant

Michael Bahtiarian, INCE Bd. Cert.
Principal

Cc: Marc Newmark, Acentech

Attached: Figures 1-3

Attachment "B"

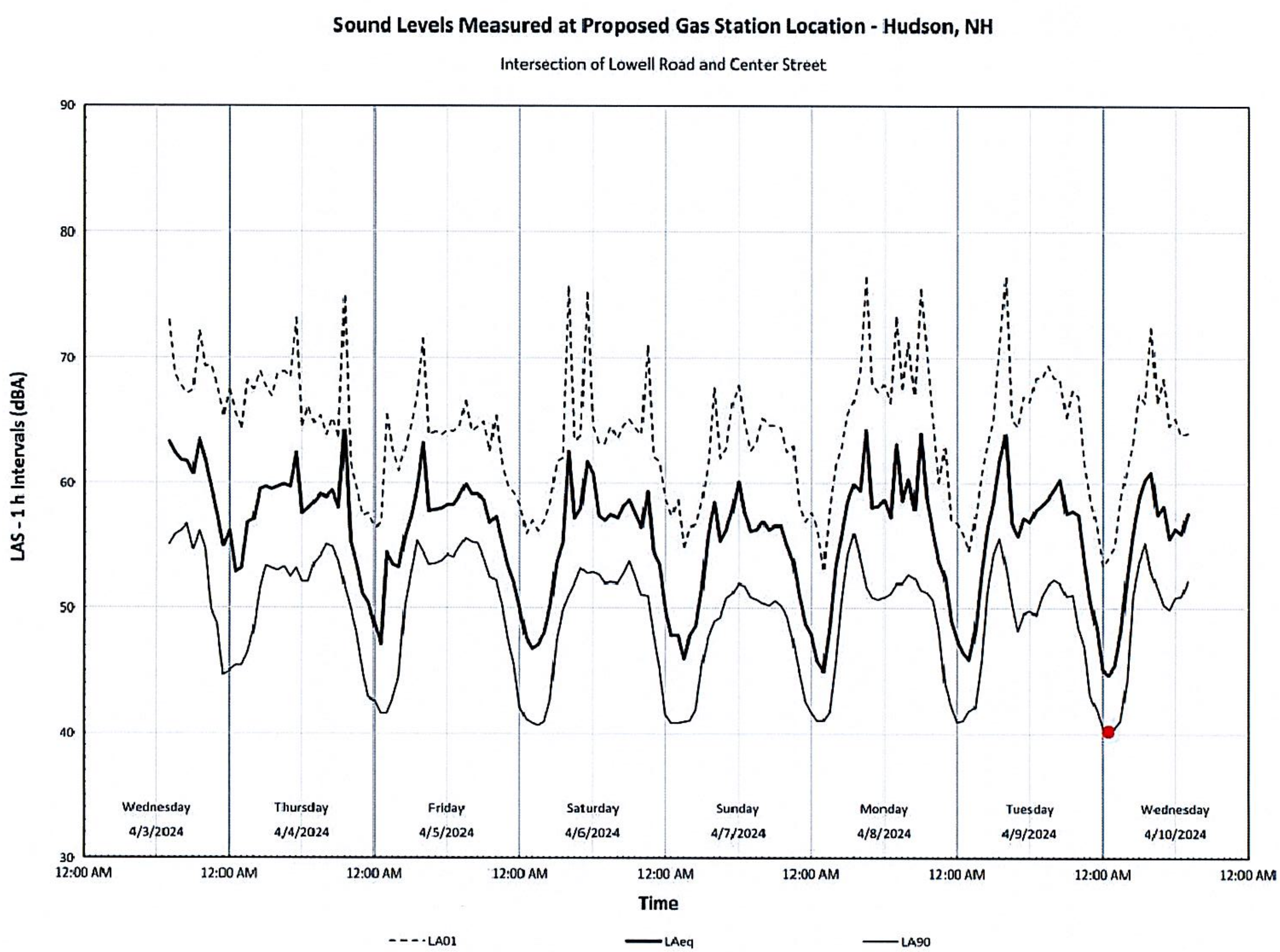
ACENTECH
ACOUSTICS TECHNOLOGY VIBRATION

Figure 1: Background Sound Monitoring Location over Aerial Imagery – Central Street and Lowell Street, Hudson, MA

Attachment "B"

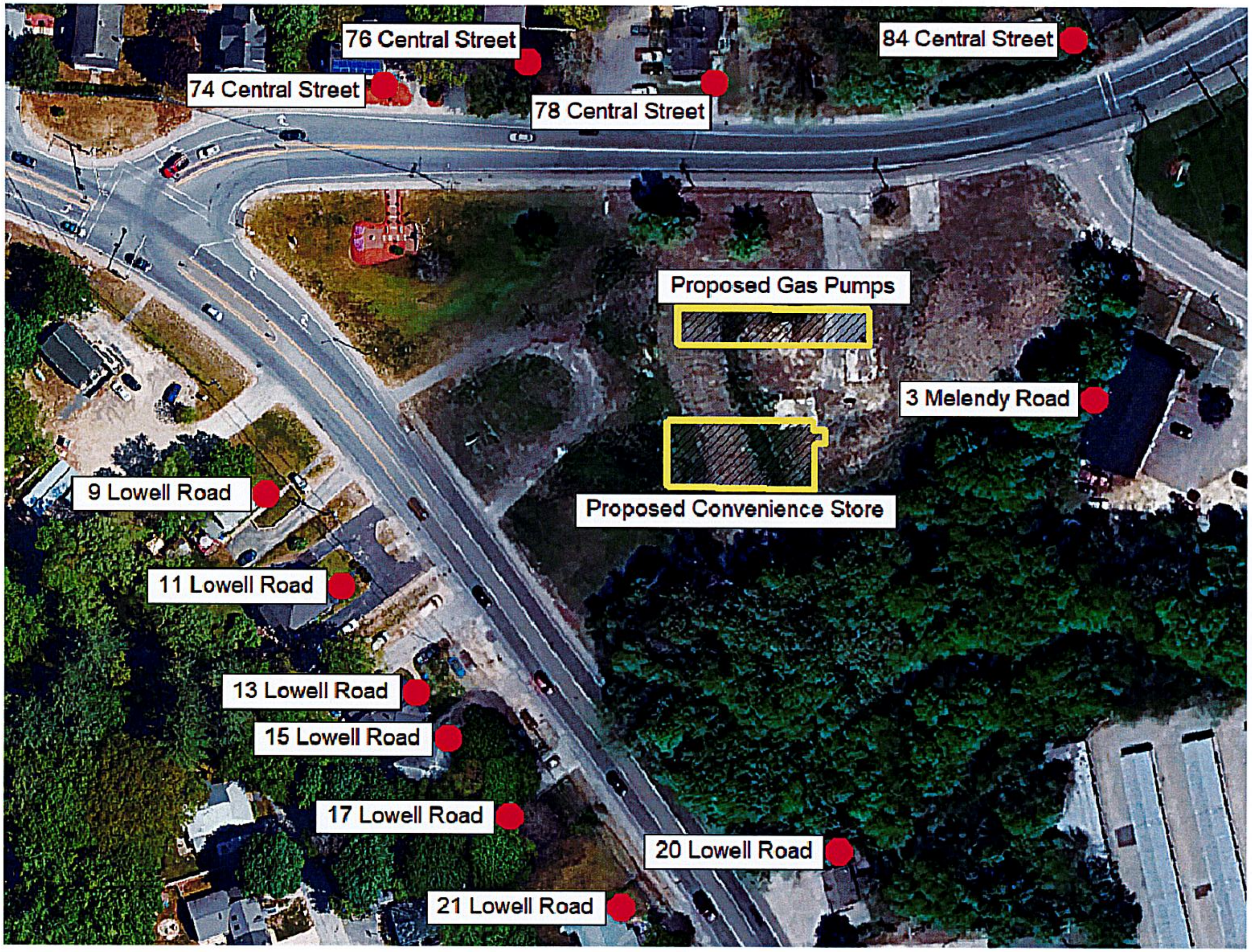
ACENTECH
ACOUSTICS TECHNOLOGY VIBRATION

Figure 2: Background Sound Monitoring Survey Results - April 3rd – April 10th, 2024
(Red dot is minimum for entire period)



Attachment "B"

Figure 3: Receptor Locations used in Sound Model



KNA Response to PB Member Comments #2

- OBSERVATION#1: In recently received PB packet materials for a different application supporting materials for an Alteration of Terrain (AoT) permit were included. The required NHDES One Stop Data Mapper reference figure for it had the layer for Asbestos Disposal Sites turned on with a symbol legend. That layer when turned on has a colored asterisk designating locations labeled as Remediation Sites. I observed several of these asterisk's points were possibly located at the Central Street / Lowell Road / Melendy Street area. Therefore, I used NHDES One Stop Data Mapper to determine more detail and find if any Remediation Sites applied to the SP# 08-23 application. There were two applicable data points. Which were 77 Central Street (aka Map 182 / Lot 217) and 1 Melendy Street (aka Map 182 / Lot 216). Both existing parcels are now vacant and are proposed to be consolidated in the SP# 08-23 application. Both lots are listed as Project Type: ASBESTOS. This implies there is a risk level of buried asbestos and NHDES Env-Sw 2100 Management and Control of Asbestos Disposal Sites not operated after July 9, 1981, regulation applies. Both these parcels are near to surrounding residential land uses.
    - QUESTION#1A: Has the applicant performed any research into NHDES records for asbestos occurrence on these two existing lots?

      Yes, and there is no available information regarding the presence of asbestos on the subject property outside of what can be found using the NHDES OneStop tool.

    - QUESTION#1B: Will the applicant agree to obtain NHDES records and supply them to the Planning Board on whether full Remediation with a Clearance Determination has been issued for the same lots?

      There is no available information regarding the presence of asbestos on the subject property outside of what can be found using the NHDES OneStop tool. If asbestos is encountered on the property, it will be addressed by a certified contractor during construction as is typical for many other projects both in town and throughout the state.

    - QUESTION#1C: If there is a possibility of buried, mixed or capped asbestos onsite and removal is proposed will the applicant agree to add a NHDES permitting requirement note on to the project plans?

      A note has been added to the plans stating the following, "According to NHDES records, there is a potential that a portion of the site, previously addressed as 1 Melendy Road, may be contaminated with buried asbestos. If necessary, the applicant will hire a contractor who is licensed by NHDES to perform work in asbestos disposal sites."

- OBSERVATION#2: The SP# 08-23 Central Gas site will be serviced by town water and sewer. The proposed land use for the site is also designated as a High load site by NHDES with surface water and groundwater contamination potential. The NHDES One Stop Data Mapper can be used to view Groundwater Classification area GA2. All five of the existing lots proposed to be consolidated are within a Groundwater Classification area GA2. Where a GA2 is a highly productive stratified drift aquifer with no land use prohibitions or active monitoring. No delineated municipal protection wellhead is noted to exist in this section of mapped GA2. However, even with town water service there can be potential nearby private wells.
    - QUESTION#2: Will the applicant agree to obtain from NHDES records a water well inventory of existing wells in the GA2 area between and down gradient of the site to the Merrimack River so possible private well users can be identified and informed of potential well contamination risks?

Attachment "C"

According to NHDES records, there is only one well in the project vicinity that is down gradient of the project site. This well is approximately 1,400 feet away from the project site and sits on the other side (south side) of First Brook. Most of the surrounding lots are serviced by municipal water.

- OBSERVATION#3: During previous public input it was mentioned that Fuller Oil Company had heating oil operations on one of the SP# 08-23 Central Gas site parcels that is proposed to be consolidated. This is verifiable in the NHDES One Stop Data Mapper and given a facility identification in the Underground Storage Tank Program. Historically, five UST were documented as removed from existing 77 Central Street (aka Map 182 / Lot 217) site in a Permanent Underground Storage Tank Closure Report. The report stated: "During the excavation, visually impacted soils were noted, near the former distribution [fill] piping. As result, the impacted soil was stockpiled. The conditions were reported to Bill Evans of NHDES. The stockpiling of this soil and future disposal was to be conducted by Fred Fuller Oil as a voluntary response program". My concern is the stockpile might have been left uncovered and not removed then contaminants would leach into underlying soil horizons.
    - QUESTION#3A: Has the Applicant researched NHDES records as to whether the stockpile was ever removed from the site and properly disposed of?

      Yes, NHDES records have been reviewed, however the status of the stockpile from 1998 is inconclusive.

    - QUESTION#3B: If no record(s) of removal are found would the Applicant agree to investigate the stockpile location for contamination before the start of proposed earthwork operations?

      A note has been added to the plans stating, "according to nhdes records, there is a potential that buried underground storage tanks may be encountered during construction. if discovered, any underground storage tanks will be removed and disposed of according to all federal, state, and local regulations."

- OBSERVATION#4: The Permanent Underground Storage Tank Closure Report also noted: "Please note, that the excavation process did not encounter or extend down to the groundwater table."
- QUESTION#4: Will the Applicant research NHDES records for possible groundwater study results in the surrounding downgradient area since the UST removals and report to the Planning Board the results of their investigations?

  There are no NHDES records of any groundwater studies in this area.

SP #08-23Central Street Gasoline Station
VHB Response to PB Member Traffic Study Comments

- **OBSERVATION #1**: At the 02-28-2024 Planning Board meeting I stated that there are known missing "**traffic related by development of others**" in the Traffic Impact Study (TIS) dated 06-30-2023 under **Future Conditions** for the period from 2023 to 2033**.** The Applicants representative response was that only off-site projects identified and agreed upon to be incorporated during preliminary conversations with the Town Departments were used for Future Conditions analysis. In what I believe to be a logical conclusion being on the corner of two major arterial roadways this Gas Station location will be a magnet to non-Hudson generated traffic passing through Hudson. Therefore, lack of these known area development traffic impacts in the TIS severely limits thorough review by the Planning Board during allowed RSA time restraints for rendering a decision.
  - **QUESTION #1**: None concerning TIS **Future Conditions.** This subject has been predetermined by others and is closed to future discussion.
  - **Response**: VHB concurs.
- **OBSERVATION #2:** Land Use Code (LUC) 945 (Convenience Store/Gas Station) and LUC 937 (Coffee/Donut Shop with Drive-Through Window) are used in this TIS for determining total estimated trip ends. If only a single LUC were used, then estimated total trip ends would be less in doubt. However, when combining LUCs it seems reasonable they may influence each other more than just being additive. The Applicants representative response at the 02-28-2024 Planning Board meeting is that per ITE analysis it is expected to cause internal site trips but not increases to total trips to the site.
  - **QUESTION #2A:** Answered at 02-28-2024 Planning Board meeting, can the applicants engineer elaborate on the accuracy of using two independent LUCs to obtain a total estimate of trip ends?
  - **Response**: VHB concurs that this question was addressed at the February 28, 2024 Planning Board meeting. Based on Institute of Transportation (ITE) methodologies, standard traffic engineering practice, and as detailed within the June 30, 2023 Traffic Impact Study, the proposed uses are projected to generate site trips independent of each other and also experience mixed-use trips in which customers may visit more than one of the proposed uses on the site (e.g., visit the coffee/ donut shop and fuel their vehicles). As stated within the September 11, 2023 Traffic Study Review letter prepared by Fuss & O'Neill (the Town's traffic peer review engineer), "The procedures that the VHB report used are reasonable and appropriate."
  - **REMAINING QUESTION #2B:** Is there an ITE LUC for a combined Convenience Store/Gas Station with a Drive-Through Window or is this **site plan a unique condition** where even the ITE has not collected any actual data for this combination?
  - **Response**: ITE Land Use Code 945: Convenience Store/Gas Station and Land Use Code 937 (Coffee/ Donut Shop with Drive-Through Window) were used in estimating site trips for the two generators as independent, stand-alone used (i.e., a convenience store/gas station and a coffee/donut shop). As detailed within the Traffic Impact Study that was accepted by the Town's traffic peer review engineer, standard traffic engineering procedures were used in estimating the number of customers who may visit more than one of the uses on the site.
  - **REMAINING QUESTION #2C:** Has the applicant's engineer observed other similar sites that have a Convenience Store/Gas Station including an **extra** Drive-Through Window combination for comparison? If so where?
  - **Response**: There are other similar facilities located in New Hampshire, including at 470 NH Route 101, 195 South River Road (also includes separate River Road Tavern, White Willow Salon & Day Spa, and ATM machine), and 8 White Avenue in Bedford; 598 Main Street in Hampstead; 124 Rockingham Road in Londonderry; 20 Roundstone Drive in Manchester; and 18 Mammoth Road in Windham (also includes a separate Krispy Krunchy Chicken restaurant).

- **OBSERVATION #3A**: I see no actual ITE LUC 945 or 937 Trip Generation data work sheet GRAPHS supplied in the TIS report only work sheet calculations in Appendix Trip Generation Calculations (~~epage 79 to 92 of 154 TIS~~). Per TIS printed page 13, ITE LUC 945 for (Convenience Store/Gas Station) uses subcategory 9-15 vehicle fueling positions for 3,760 sf. Reading the fine print on the ITE Trip Generation Worksheet (~~epage 84 of 154~~) it lists SETTING / LOCATION as General Urban / Suburban for it.
  - **QUESTION #3A1:** Are these the only general parameters used to determine the quantity of trip ends, with NO possible adjustments for such things as the location being influenced by main corridor traffic volumes on multiple site frontages or possibly operating age in years of facility?
  - **Response**: The trip-generation estimates for the convenience store/gas station component were based on the square footage of the convenience store. Using the number of vehicle fueling positions as the independent variable would result in less calculated site trips. Therefore, the square footage trip-generation methodology was used within the traffic study to evaluate a worse-case condition.

    As documented within the ITE Trip Generation Handbook, the traffic engineer should use the appropriate independent variable that is accurately projectable for a development site. Basing the estimated site trips on the volume of adjacent street traffic may not provide an accurate methodology because the existing and future traffic volumes evaluated within the traffic study may not be realized due to land development projects in New Hampshire being required to increase traffic counts to represent peak-month, pre-pandemic conditions and applying an overestimated growth rate. Therefore, professional engineering judgment was to use the square footage of the proposed convenience store as the independent variable. The Town's traffic peer review engineer deemed the methodologies used within the Traffic Impact Study to be "reasonable and appropriate."
  - **QUESTION #3A2:** Do all of the ITE LUC 945 for (Convenience Store/Gas Station) uses subcategory 9-15 vehicle fueling positions include dispensing of diesel fuel?
  - **Response**: The description for ITE Land Use Code 945: Convenience Store/Gas Station states that, "*A convenience store/gas station is a facility with a co-located convenience store and gas station. The convenience store sells grocery and other everyday items that a person may need or want as a matter of convenience. The gas station sells automotive fuels such as gasoline and diesel.*"
  - **QUESTION #3A3:** The public mentioned on 01-24-2024 and again on 02-28-2024 if there will be any Highboy diesel fuel filling proposed on this site. Please define it and answer if there will be.
  - **Response**: The proposed development will not include Highboy diesel fuel.
- **OBSERVATION #3B**: Per TIS printed page 13 ITE LUC 937 (Coffee/Donut Shop with Drive-Through Window) only lists one parameter of 800 sf to determine trip ends.
  - **QUESTION #3B**: Same as earlier, is this the only general parameter used to determine the quantity of trip ends, with NO possible adjustments for such things as the location being influenced by main corridor traffic volumes on multiple site frontages or possibly operating age in years of facility?
  - **Response**: The trip-generation estimates for the coffee/donut shop were based on the square footage of the restaurant. Similar to the response to Question #3A1, the use of the volume of adjacent street traffic as the independent variable may not produce an accurate methodology in estimating the site trips. The trip-generation methodologies used within the Traffic Impact Study were deemed to be "reasonable and appropriate" by the Town's traffic peer review engineer.
- **OBSERVATION #4**: I wonder about the correlation to this site with the number of data points used in the missing ITE LUC 945 or 937 data work sheet GRAPHS to establish the basis for estimated trip ends at various peak hours. A previous ITE LUC data worksheet graph used on another site plan application had only two data points on it and was used to determine peak hour trips. The validity of those data points listed, and correlation of the graphical fitted curve did not even compare well to that proposed project being reviewed by the PB. I do NOTE it appears the number of data point studies used on this application for LUC 945 are in the thirties (epage 84) and for LUC 937 (epage 85) they range from 34 to 78 for different

peak hours. However, it is unknown if these data points are located at SITES with an intersection of two major arterial roadways. Also, it is very important to know about the data points used in the GRAPH as to whether a SIGNIFICANT CLUSTER of them on the graphical fitted curve falls close to what parameters are being proposed for this project to determine trip ends.

- **QUESTION #4**: Will the applicant agree to supply the PB with additional ITE LUC 945 and 937 GRAPHICAL work sheets in packet materials for clarification and examine how they validate the estimated trip end conclusions?
- **Response**: The trip-generation calculations provided within the Appendix of the Traffic Impact Study are consistent with ITE methodologies and standard traffic engineering practice. The Town's traffic peer review engineer determined that the procedures used in estimating the site trips "are reasonable and appropriate" and "the ITE Trip Generation Manual, 11th edition data and chosen land uses for the proposed site are accurate."

- **OBSERVATION #5A**: In the TIS I have studied Figure 8 titled **2023** Build Peak Hour Traffic Volumes (~~epage 20 of 154~~) and Figure 9 titled **2033 Peak Hour** Traffic Volumes (~~epage 21 of 154)~~ for directional distribution of the traffic volumes. I note the trips (58) entering / exiting the site are the same for **2023** build as they are for **2033** build. However, the estimated traffic counts on both the Central St and Lowell Rd major arterials have been shown to grow over the same 10-year period. This is even without the missing and extra "**traffic related by development of others**" I noted earlier in my TIS analysis. It doesn't seem reasonable to this layman why the corridor traffic counts can increase but ITE Trip Generation trip ends entering / exiting the site remains stagnate over the same 10-year period. I wonder why ITE LUC trip generation values **remain static** while corridor traffic volumes increase.
  - **QUESTION #5A:** Is there no growth in clientele for a gas station like well-run restaurants, please explain why 2023 Build site trip in and out values are sufficient for use as 2033 Build values?
  - **Response**: The trip-generation estimates for the proposed uses were based on the square footage of the facilities (i.e., the convenience store and the coffee/donut shop). As previously noted in responses to Questions #3A1 and #3B, estimating the site trips using the volume of adjacent street traffic may not produce an accurate methodology in estimating the site trips because of the adjustment factors required to be used as part of land development projects in New Hampshire. The Town's traffic peer review engineer accepted the methodologies used within the Traffic Impact Study.
- **OBSERVATION #5B:** The TIS uses a Distribution of capture Estimation Tool for ITE By-Pass Trips concept in Figures 5, 6 &7 (~~epages 17 to 19~~) for distribution of 2023 trips in and out of the site. Logically one would believe the same ITE By-Pass Trips concept for corridor traffic volumes would be used as a standard engineering practice to adjust future ITE LUC 2033 total trips in and out of the site upward for increases in corridor volumes as a site matures.
  - **QUESTION #5B:** Please comment as to why an increase to 2033 trips in and out of the site trip generation volumes do not use the same Estimation Tool method as for 2023 estimations?
  - **Response**: Please see responses to Questions #3A1, #3B, and #5A.
- **OBSERVATION #5C:** Again, an Estimation Tool is used for **New Trips** concept used in Figures 5,6 &7 for 2023 trips in and out of the site use the same values for 2033 estimates.
  - **QUESTION #5C:** Please explain why New Trip values remain the same for 2023 and 2033 build conditions. I would think there would be some increase in new customer growth due to a ten-year increase in corridor traffic volume.
  - **Response**: Please see responses to Questions #3A1, #3B, #5A, and #5B.
- **OBSERVATION #5D:** It appears to me the lack of estimated growth effect of the Lowell and Central corridors for quantities and distribution of site in and out turning movements for 2033 understates what is probably a more realistic total 2033 ITE LUC trip generation estimate resulting in under estimation of 2033 **LOS impact on the Lowell / Central intersection** in the TIS.
  - **QUESTION #5D:** Will the applicants engineer give a justification and clarification of why 2023 and 2033

ITE LUC trip generation estimates and turning movements can be the same and static in the TIS?

- **Response**: Please see responses to Questions #3A1, #3B, #5A, #5B, and #5C.

- **OBSERVATION #5E:** Looking at the worksheet calculations for both LUCs I see no quantity for External Trips By Mode – Non-Motorized meaning Person- Trips. This site is near a school and multiple residential homes. I would think that there would be a significant or notable draw of pedestrians traveling by foot to the convenience store.
  - **QUESTION #5E1:** Am I missing something, does the TIS Estimation Tool ignore pedestrian foot traffic to this site which could be used as an indicator for necessary public safety considerations for improvements to off-site cross walks and internal site pedestrian movements?
  - **Response**: The ITE trip-generation methodologies presented within the Traffic Impact Study were used for evaluating the vehicular traffic impacts on the adjacent roadway system. Although there is limited ITE data in estimating pedestrian site trips for the proposed uses, there are existing pedestrian facilities provided along Lowell Road, Central Street, and at the signalized intersection to accommodate foot traffic. In addition, the proposed development will provide pedestrian connections within the site.
  - **QUESTION #5E2:** Will the Applicant agree to or can the External Trips By Mode – Non-Motorized section for estimated pedestrian trips be upgraded due to the location of this site.
  - **Response**: Please see response to Question #5E1.
- **OBSERVATION #6A:** It appears a Lowell Road right turn in SLIP lane is proposed for the site under Improvements in the TIS (~~epage 27~~). A warrant analysis is given (~~on epage 28~~) and calculations a supplied in an Appendix of the TIS.
  - **QUESTION #6A:** I see no right turn Slip lane for east bound traffic on Central Street to help alleviate possible obstructions to free flow traffic being proposed or an easement for dedication of ROW widening if corridor traffic counts exceed the 10-year window? Again, we already know that future traffic related to "**traffic related by development of others**" Non-Hudson generated pass-thru traffic seems underestimated.
  - **Response**: In accordance with National Cooperative Highway Research Program (NCHRP) Report 457 guidelines, the 2033 Build traffic volumes presented in the Traffic Impact Study for the Central Street site driveway intersection do not meet the warrants for a left-turn lane along Central Street westbound, a right-turn lane along Central Street eastbound, or a two-lane approach on the proposed site driveway.
- **OBSERVATION #06B:** VHB letter dated 10-02-2023 on page 4 states: "Improvements for the Town of Hudson to consider would be to upgrade the **pedestrian facilities** with detectable warning fields at the Lowell Road signalized intersection and the pedestrian crossing messaging at both signalized intersections (Walk and Don't Walk, countdowns". I would think the Convenience store would be a significant attraction for this pedestrian traffic.
  - **QUESTION #6BA:** Would the applicants professional engineer submit a more thorough analysis of needed pedestrian off site crosswalk markings and signal messaging at the Central / Lowell Road intersection on plans and in the TIS?
  - **Response**: A documented within VHB's October 2, 2023 response to comments letter, consideration can be given to installing detectable warning fields at the Lowell Road and Central Street signalized intersection and upgrading the pedestrian messaging to Walk/Don't Walk and countdowns.
- **OBSERVATION #7A:** Left turning movements into the site from Central Street WB traffic and Map 182 Lots 218-1 and 218-2 consolidations were examined and discussed at the 02-28-2024 Planning Board Plan meeting.
  - **QUESTION #7A:** I have no future questions on this aspect of the TIS.
  - **Response**: No response is required.
- **OBSERVATION #7B - NHDOT Surplus Land Disposal**: This was examined and discussed at the 02-28-

2024 Planning Board Plan meeting.

- **QUESTION #7B:** I have no future questions on this aspect of the TIS.
- **Response**: No response is required.

- **OBSERVATION #8:** I see no dedicated left turn lane out of the site onto Central Street on plans or in the TIS analysis. It appears to this layman that the nearby traffic light will release pulsed traffic from a Central left turn to go eastward on it, followed by pulse release of Lowell NB right turn onto Central EB. These pulse releases could cause a problem in the short driveway queuing area for exiting the site. I see queue calculations for the Central / Lowell intersection but none for site exit trips for right or left turns examined in the TIS.
  - **QUESTION #8A:** Has the applicant examined that there is adequate site exiting **queuing** available to access Central Street to not disrupt onsite vehicular movements? If so, how was it determined?
  - **Response**: As shown within the Traffic Impact Study, the maximum 95th percentile queue length on the Central Street site driveway is projected to be 72 feet. As confirmed by KNA at the February 28, 2024 Planning Board meeting, this vehicle queue would be able to be accommodated on-site without impacting internal circulation.
  - **QUESTION #8B:** has a dual site exit lane design ever been studied such as one lane for left turns out and another lane for right turns out?
  - **Response**: As previously noted in response to Question #6A, the 2033 Build traffic volumes presented in the Traffic Impact Study do not meet the NCHRP warrants for a two-lane approach on the proposed Central Street site driveway.
- **OBSERVATION #9:** I see no designation of amount of **queuing** supplied for the two segments of the total drive-thru path for LUC 937 (Coffee/Donut Shop with Drive-Through Window. Queuing lengths are needed at the Menu Board where approximately 2 are provided and then again at the drive-thru window where approximately 6 are provided.
  - **QUESTION #9A:** What are the queuing vehicle quantities provided for each segment and how was it established that they are adequate for this site?
    - The first concern is menu board queuing; has it been verified as adequate for this type of facility. I'm concerned with long lines and disturbance of other vehicular travel paths on the site.
    - The second concern is queuing between menu board and dispensing of coffee and food products at pickup window. Is this known to be adequate to not impact the menu board location?
    - **Response**: KNA determined the drive-through queueing was in compliance with Section 275-8.C(2)(c)[5] of the Town of Hudson Code, in which 12 vehicle stacking spaces are required to be provided for eating and drinking establishment with drive-through window service.
  - **QUESTION #9B**: I have noticed existing problems with queuing at the Flagstone Drive Starbucks and Dunkin Donuts facilities in Hudson during peak hour traffic periods. Is there any ITE data from similar operations to the one being proposed to assure proposed queuing on this site is adequate for this proposed drive-thru?
  - **Response**: Please see response to Question #9A.
- **OBSERVATION #10:** The Hudson Master Plan chapter for Transportation has information and recommendations for improvements to the Hudson transportation network such as: A statement that **"The Town should employ <u>access management techniques</u> for the purpose of preserving roadway capacity and ensuring safe movement for vehicles entering and exiting curb cuts and side roads."** Central Street is noted as one of these affected corridors. **One aspect of access management is reduction of curb cuts onto them**. The intent of these **access management techniques** seems to be even more important for significant volume trip generator curb cut driveways such as currently being proposed in this Central Gas site plan application.
  - **QUESTION #10:** Page 3 of the VHB 10-02-2023 letter notes TDM Traffic Demand Management but does

not mention or examine reduction in CURB CUTS. Has the applicant investigated an alternative entrance / exit location on Melendy Street instead of the proposed Central Street curb cut for a beneficial **access management technique** to protect the corridor? **IF NOT WHY?**
  - **Response**: Access was not considered on Melendy Road due to the limited site frontage and the placement of such driveway along this short segment may result in safety and operational concerns at the Central Street and Melendy Road intersection.
- **OBSERVATION #11:** Just about everyone in Hudson has wondered why the sharp right turning movement on NB Lowell onto Central EB is not addressed. At the 01-24-2024 PB meeting there was public input testimony stating something like:" why not use this time as an opportunity to increase the insidious turning radius that currently exists at the location of this parcel
  - **QUESTION #11:** Why are no easements or preliminary plans or studies being proposed by the Applicant that would also benefit them if a remedy solution for that sharp turning movement can be determined during this Application review?
  - **Response**: An easement is shown on KNA's site plans. Of importance to note, the Town of Hudson owns property directly on the southeast corner of the intersection (Tax Map 182, Lot 218) that is not under the control of the applicant.
- **OBSERVATION #12:** During the 02-28-2024 Planning Board meeting I think it was mentioned some other communities have specific guidelines for Traffic Impact Studies.
  - **QUESTION #12:** Would the Applicants Engineer please share who these communities are to educate the Planning Board?
  - **Response**: Section 600 of the Town of Hudson's Engineering Technical Guidelines & Typical Details identifies requirements in the preparation of Traffic Studies. Based on recent experiences preparing traffic studies for land development projects, developing corridor evaluations, and conducting third-party peer reviews within other New Hampshire municipalities, VHB has identified that the following communities have detailed traffic study guidelines:
    - City of Concord
    - Town of Hooksett
    - Town of Londonderry
    - City of Manchester
    - Town of Merrimack
    - City of Nashua

Cumberland Farms

10 Morgan Road Hudson NH 03051

This property has two driveway cuts on rte 102 and one on Morgan road.

This property also has a connection to a CVS store

Attachment "D"

Google Maps 10 Morgan Rd

Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

Attachment "D"

Cumberland Farms

10 Morgan Road Hudson NH 03051

This property has two driveway cuts on rte 102 and one on Morgan road.

This property also has a connection to a CVS store

Attachment "D"

Google Maps 10 Morgan Rd

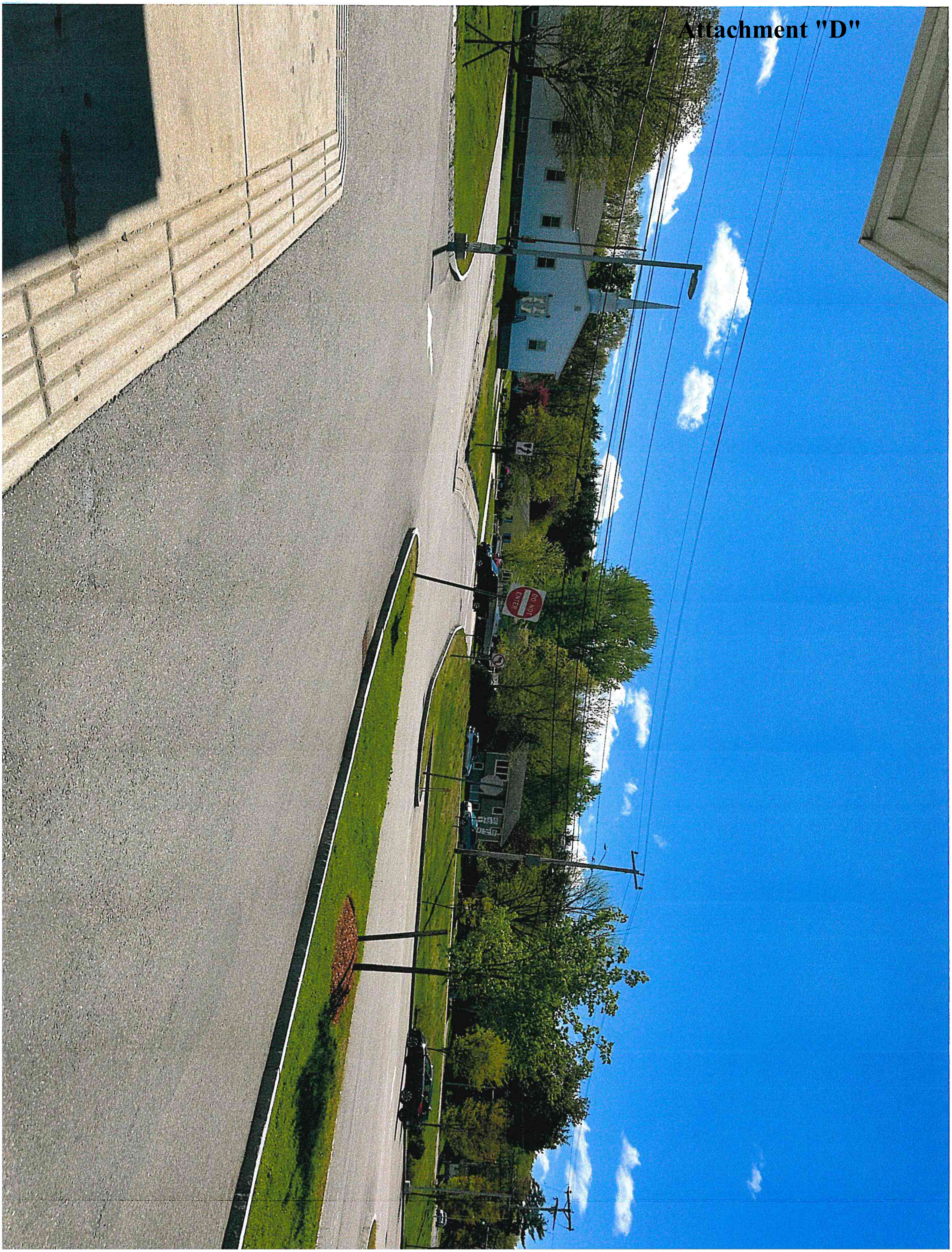
Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

Attachment "D"

Attachment "D"

Attachment "D"

Attachment "D"



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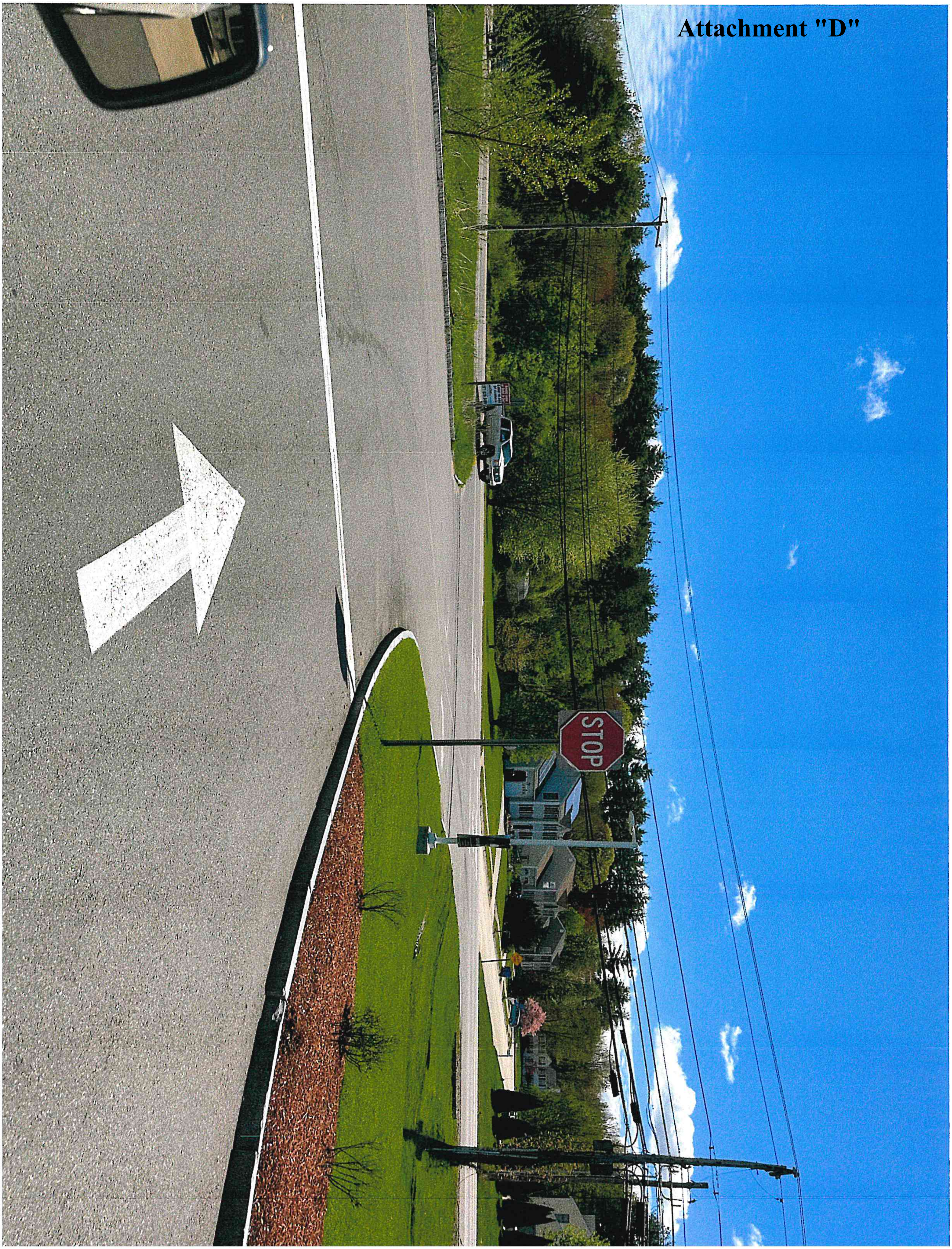

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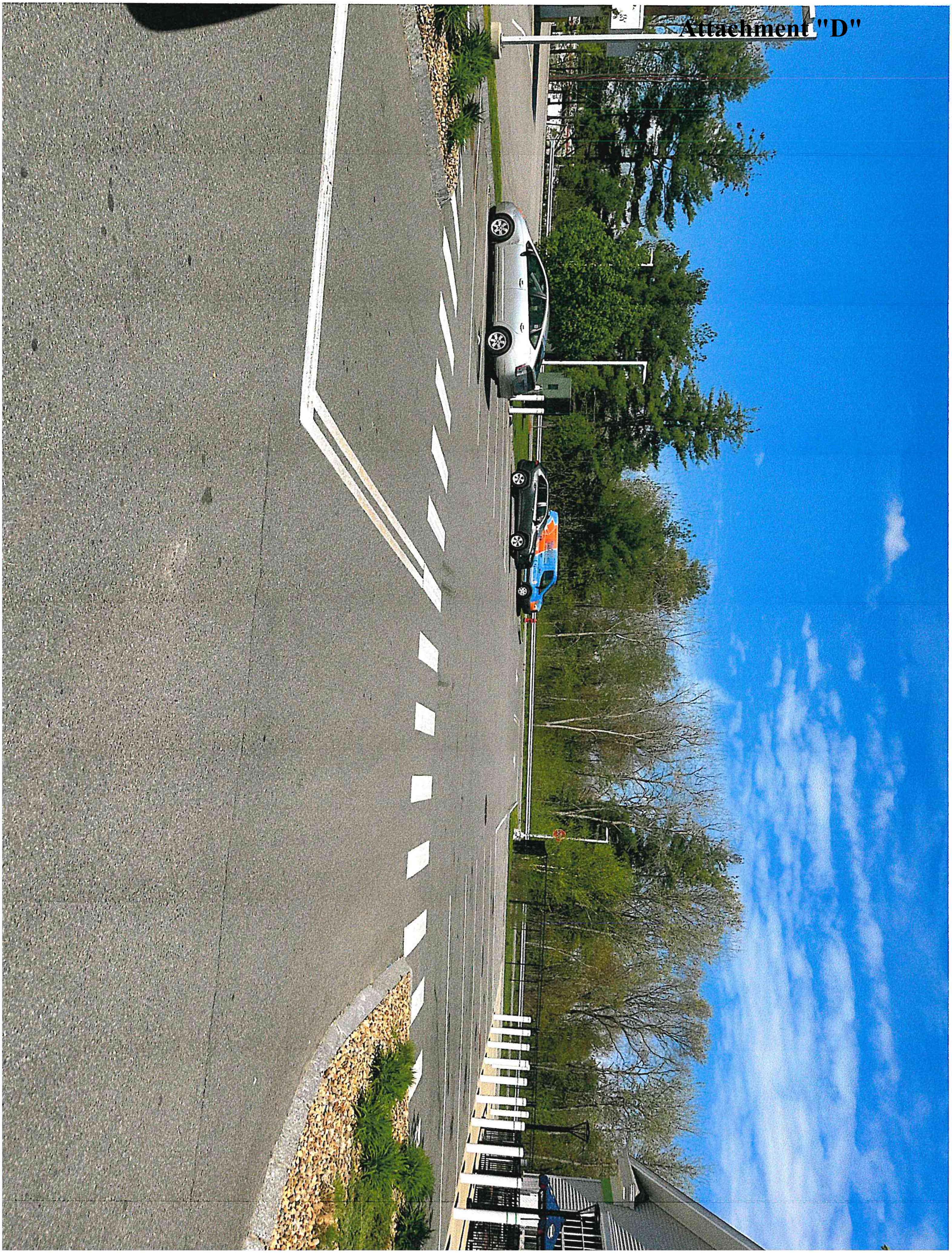


Circle K Gas Station

329 Derry Road Hudson NH 03051

This property has one driveway cut on rte 102 and one on Robinson road.

This property previously had a drive thru Dunkin Donuts until they relocated to their own building across the street

This location also has a car wash locate on site

Attachment "D"

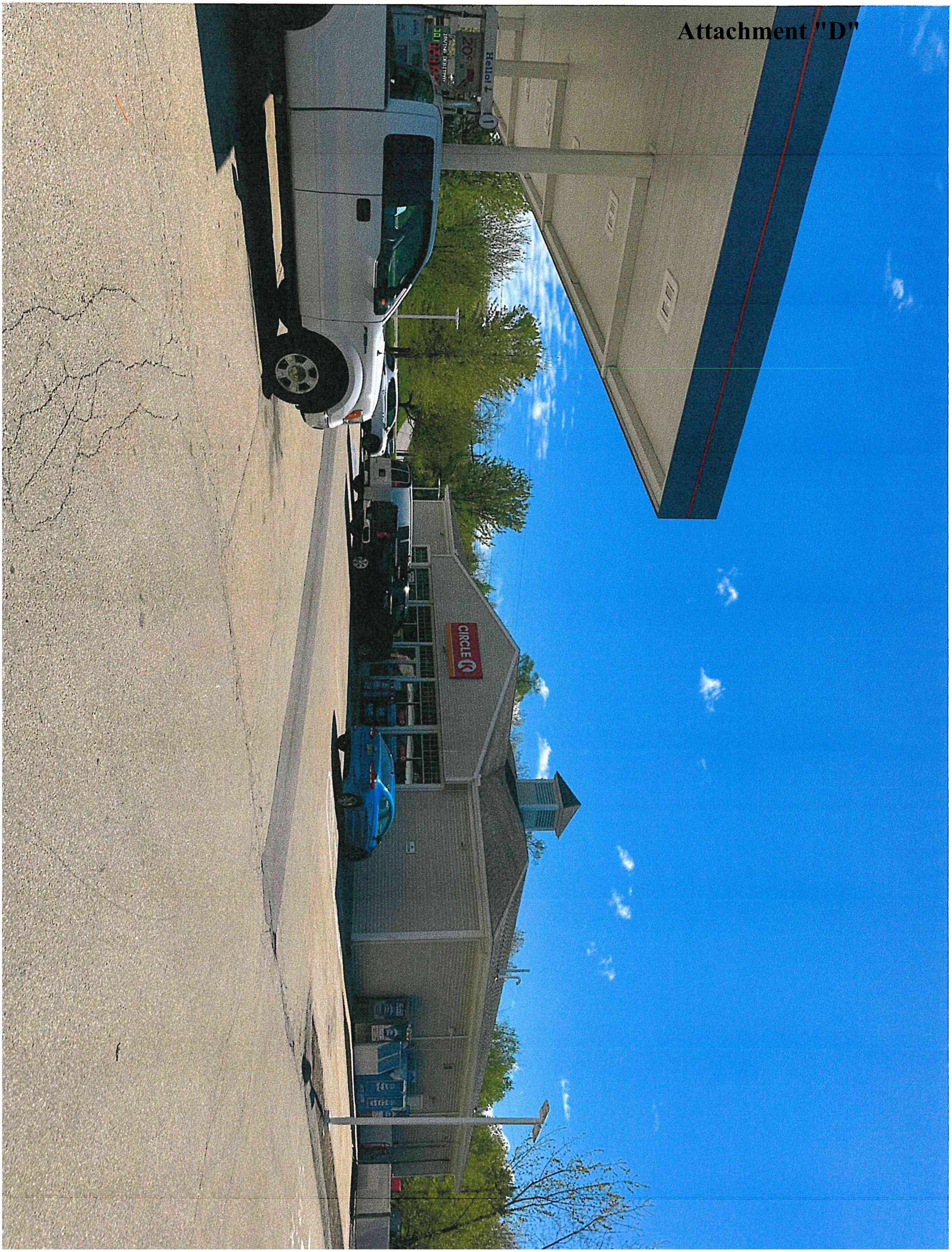
Google Maps 329 Derry Rd

Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

Attachment "D"

Attachment "D"

Attachment "D"



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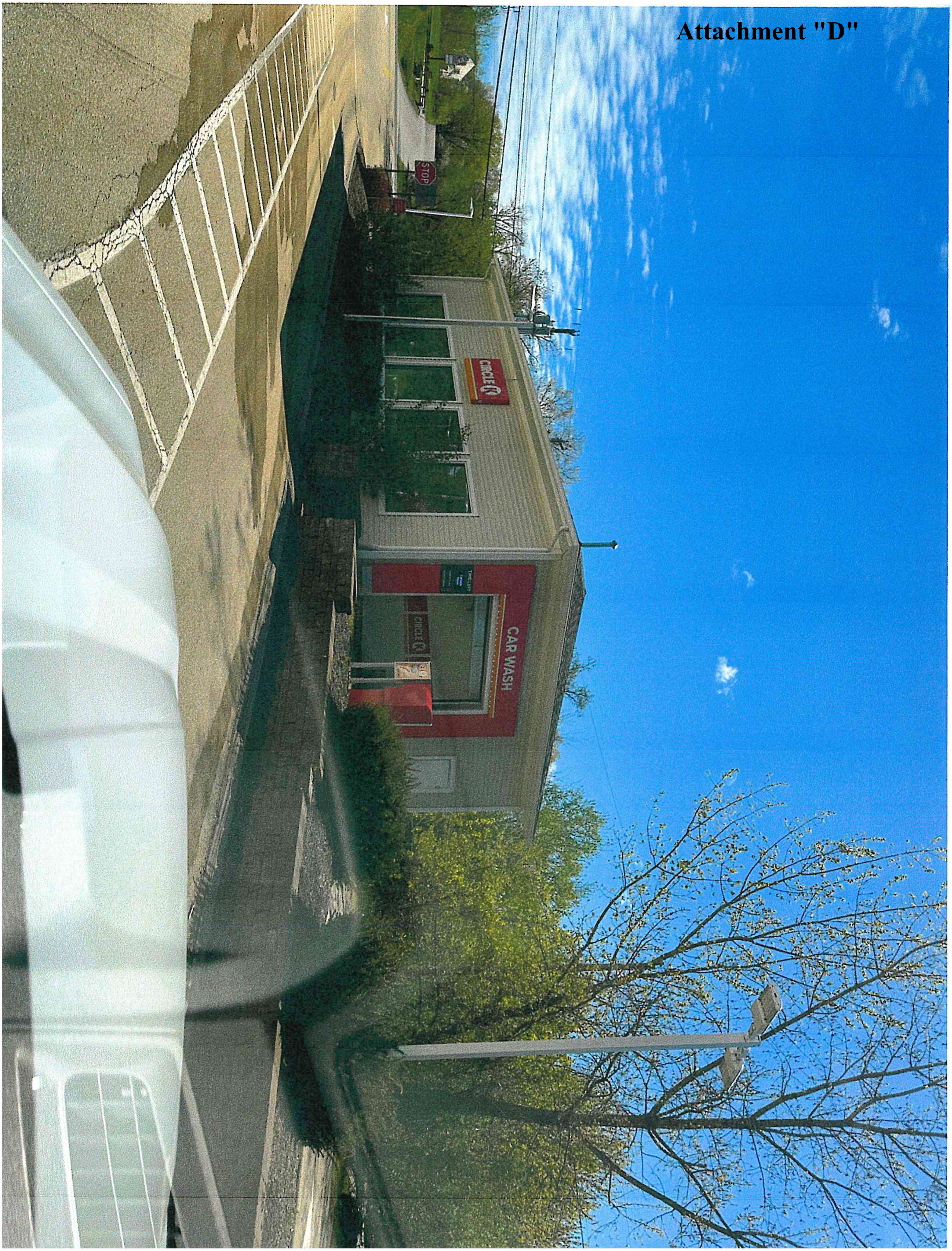

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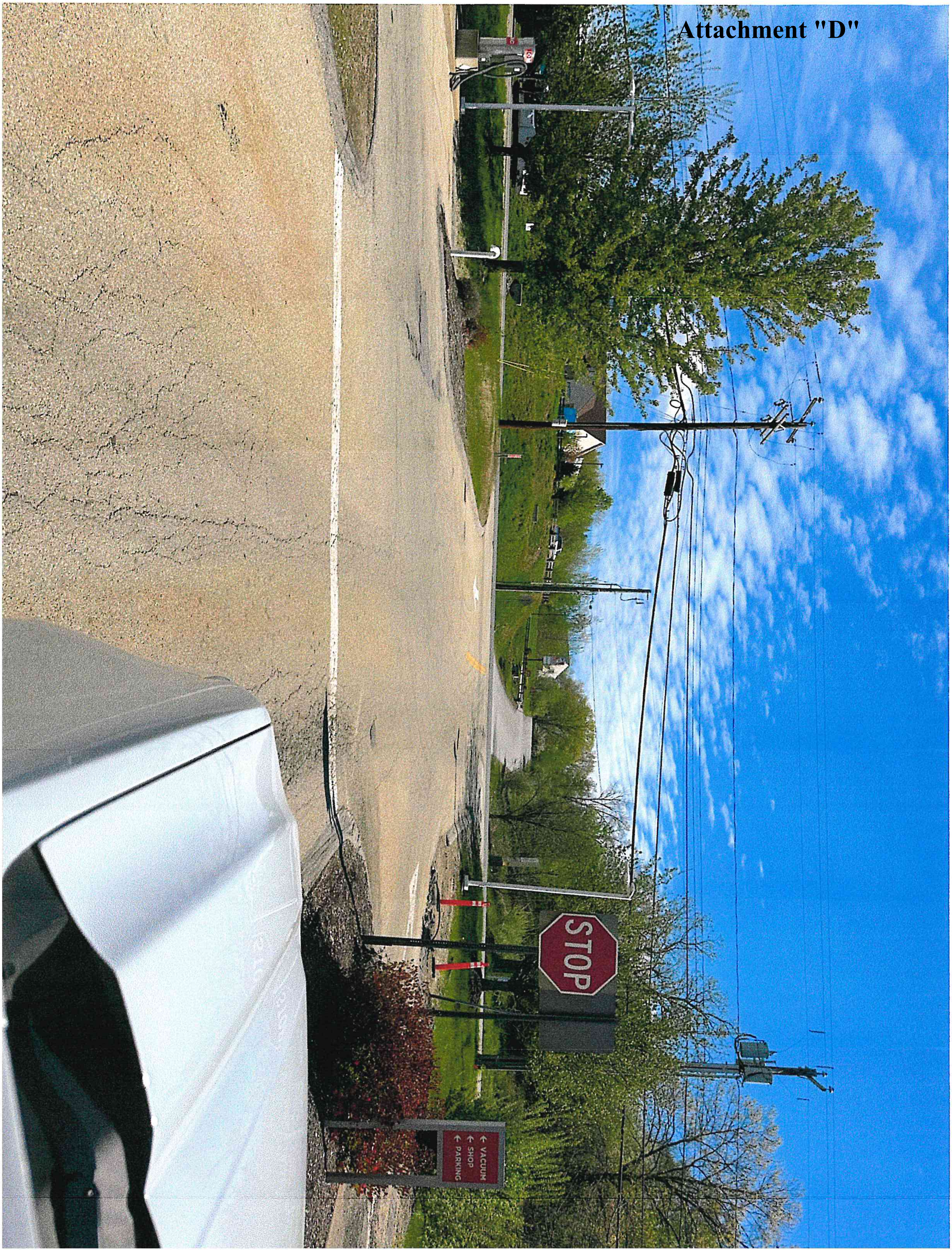


Waterhouse gas station

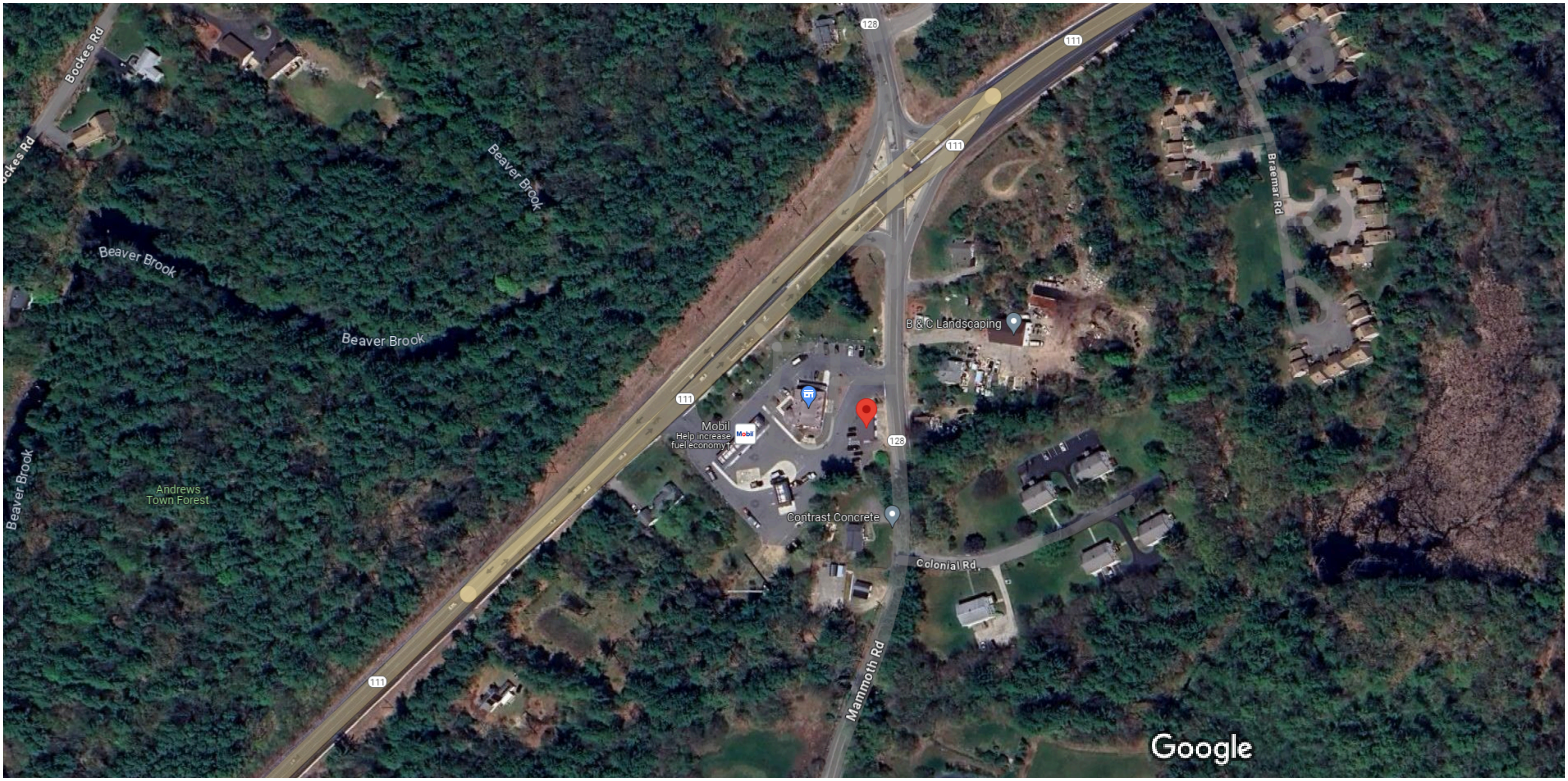
18 Mammoth Road Windham Nh 03087

This property has two drive way cuts one on rte 111 and one on Mammoth Road .

This location also has a drive thru honey dew donuts

Attachment "D"

Google Maps 18 Mammoth Rd



Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

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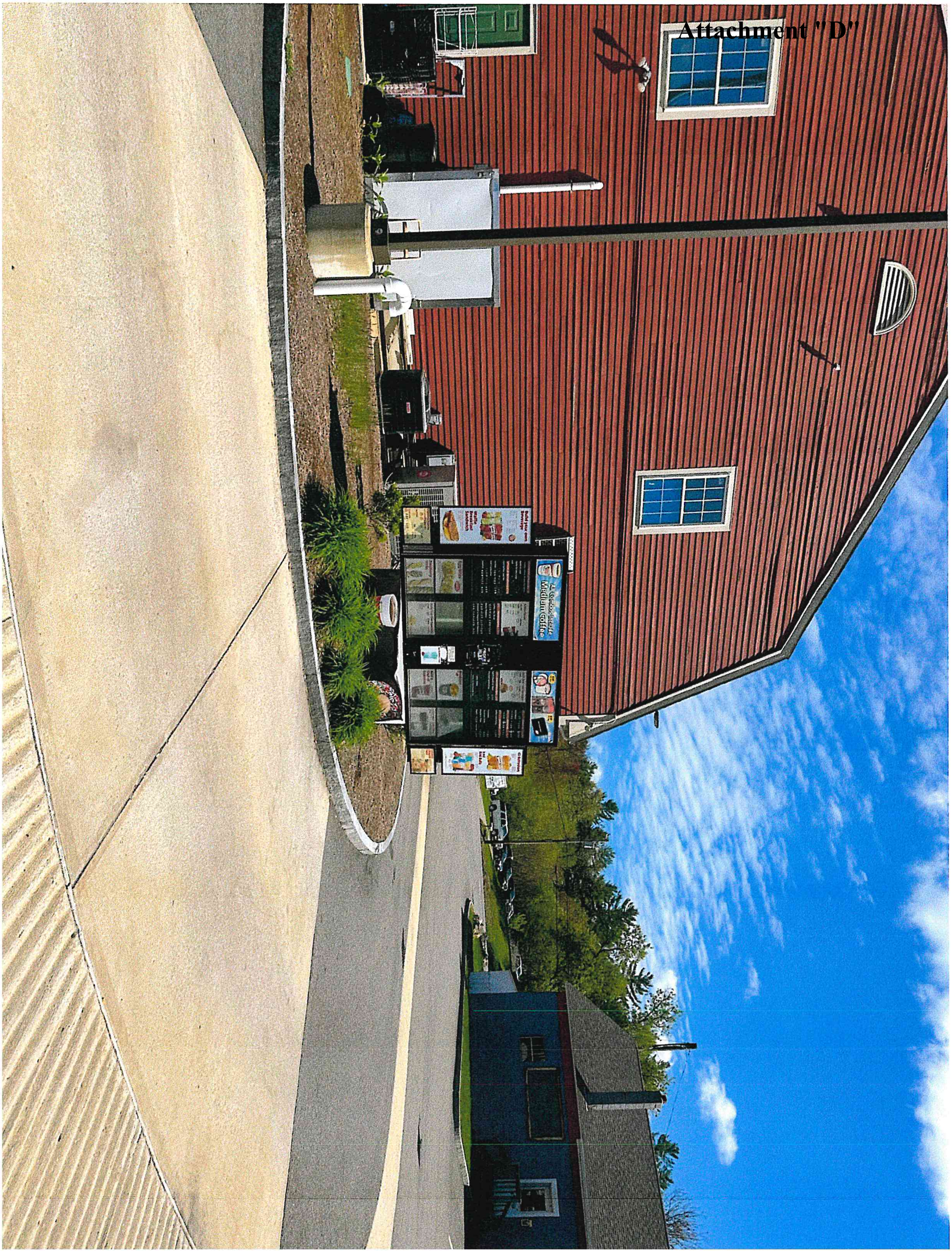

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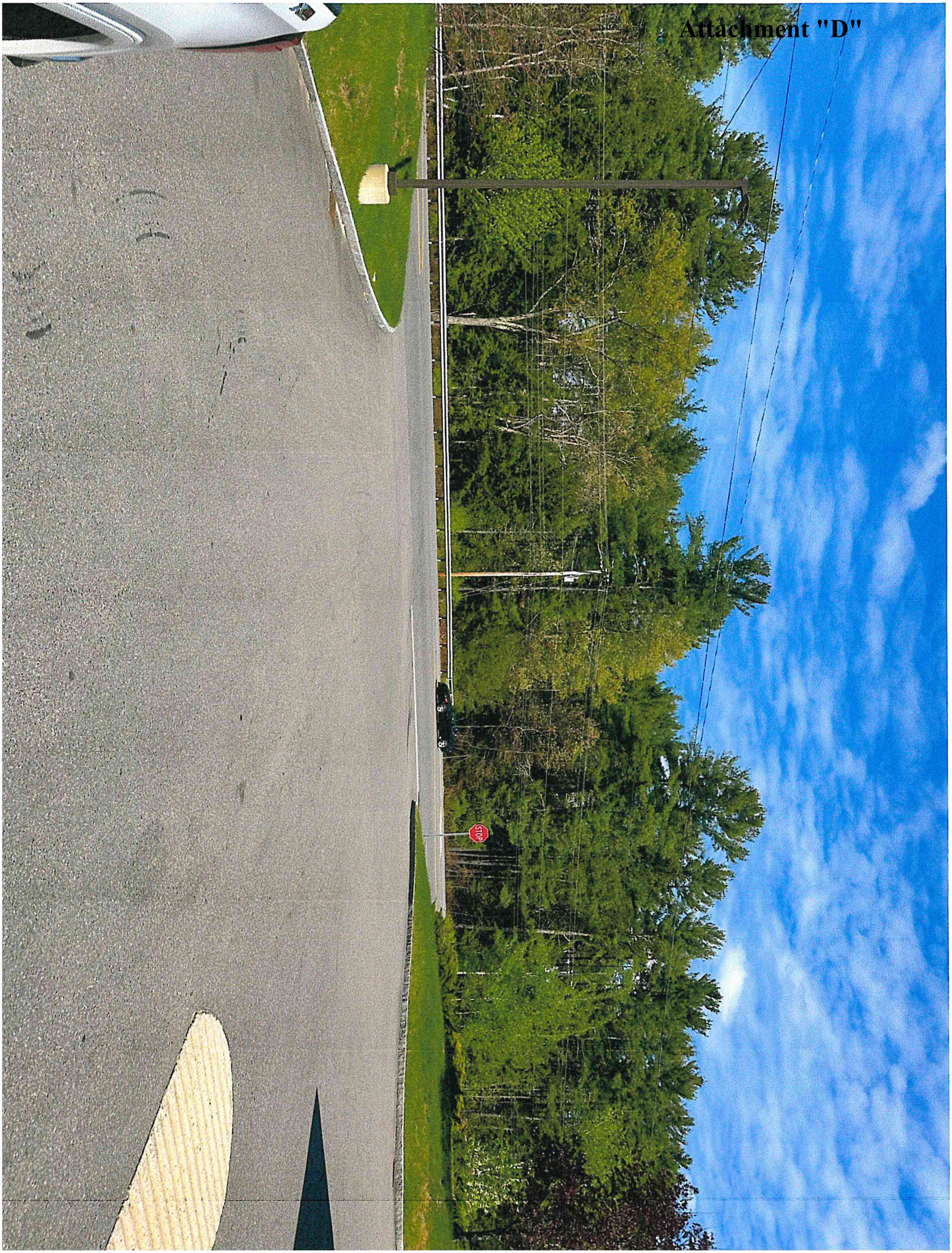


Rusty Lantern

4 Executive Drive Hudson NH 03051

This property has two drive way cuts one on executive drive and one on Lowell road.

This business is also open 24 Hours

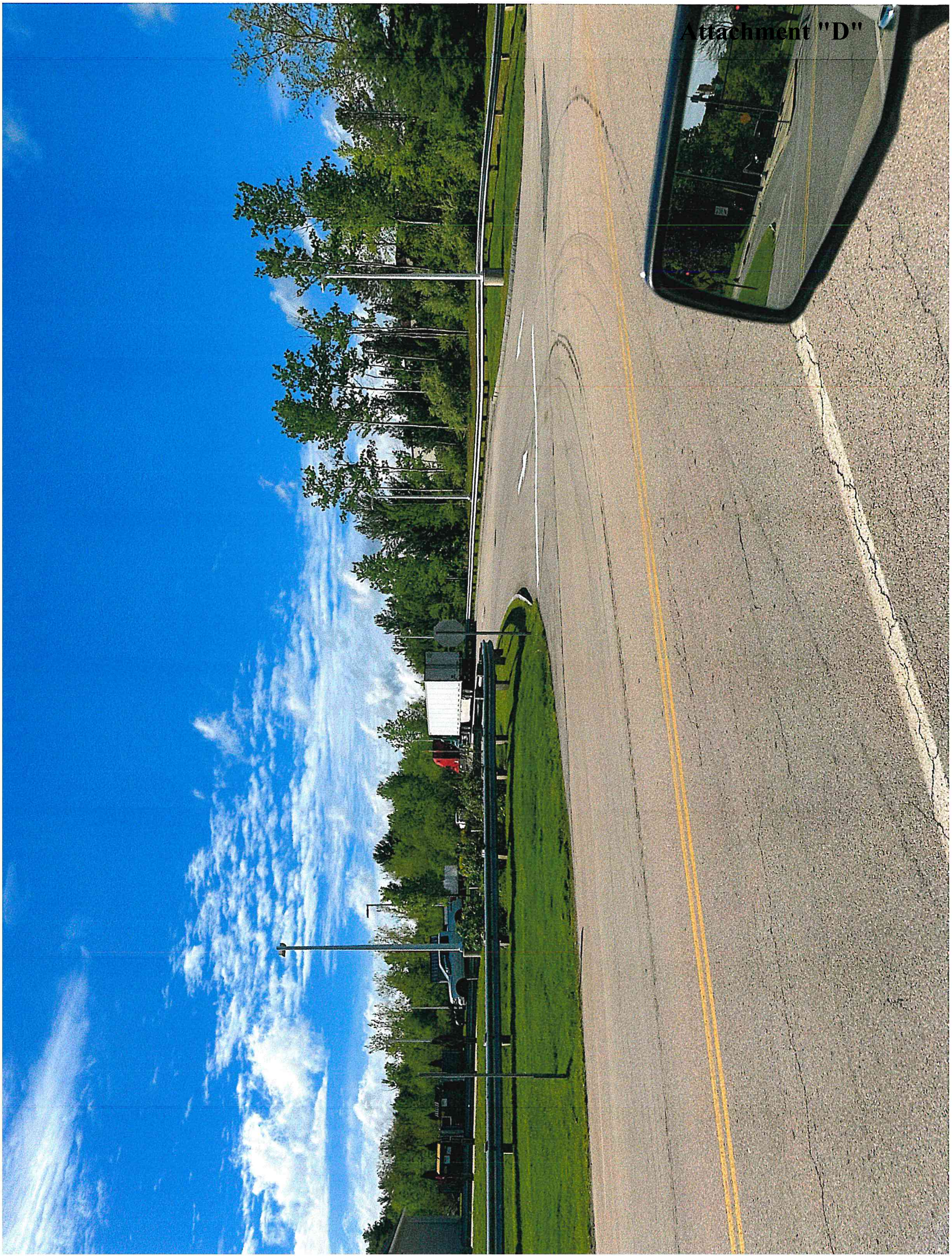
Attachment "D"

Google Maps 4 Executive Dr

Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

Attachment "D"

Attachment "D"



Attachment "D"

Irving Gas Station

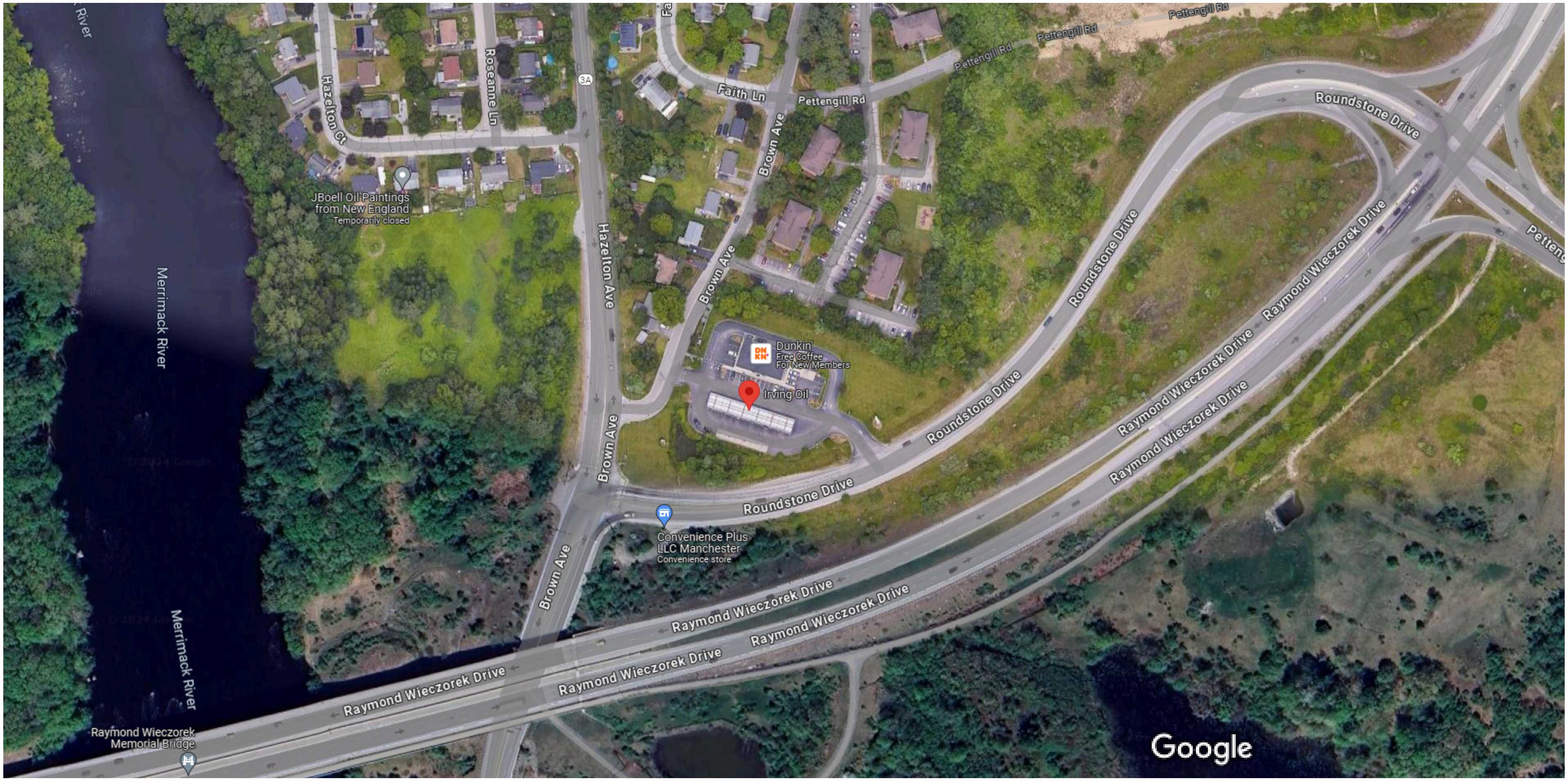
20 Roundstone Drive Manchester NH 03103

This property has one driveway cut on Roundstone Drive and one on Brown Ave .

This property has a drive thru Dunkin Donuts

Attachment "D"

Google Maps Irving Oil



Imagery ©2024 Airbus, Maxar Technologies, Map data ©2024 100 ft

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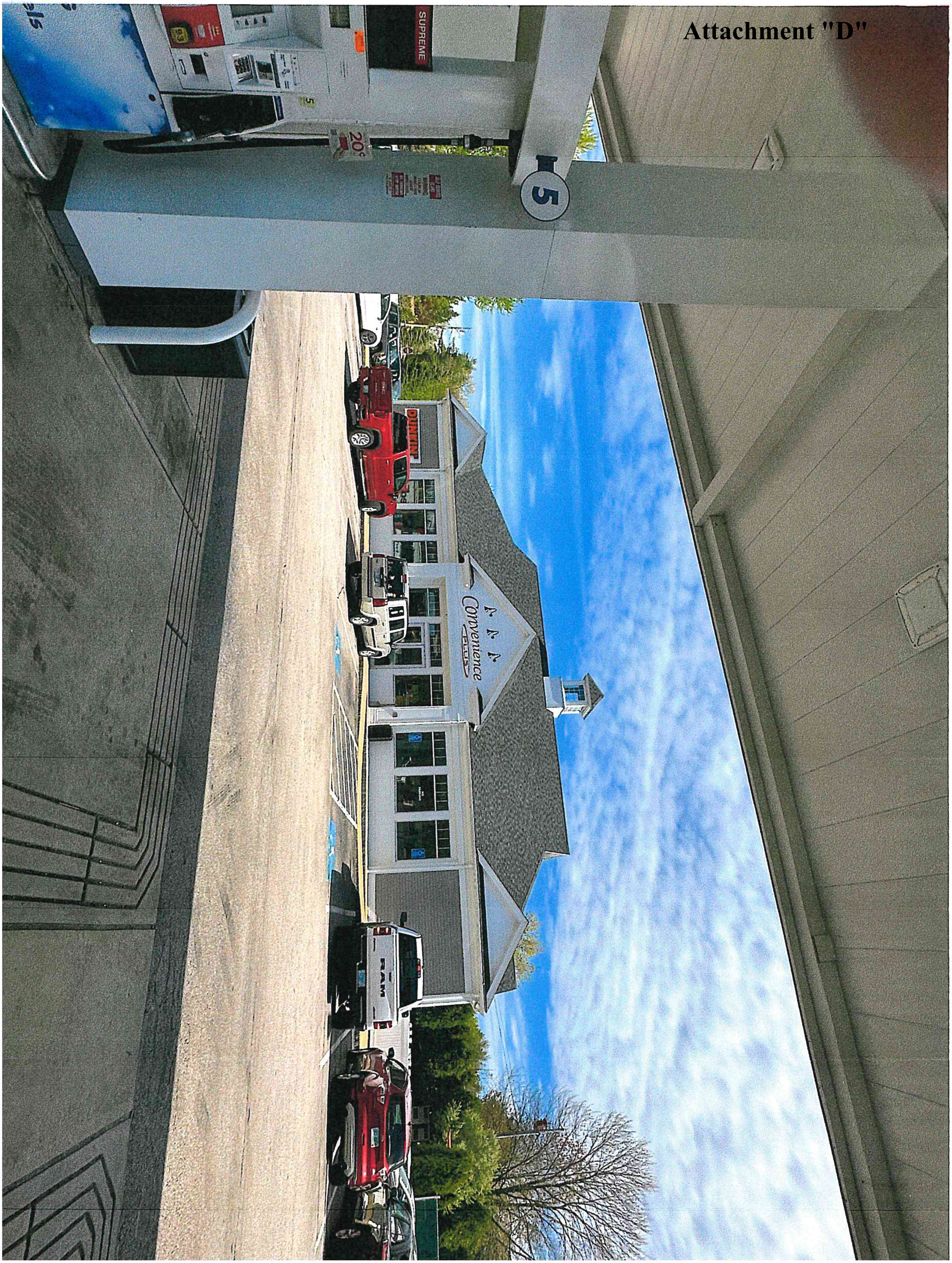

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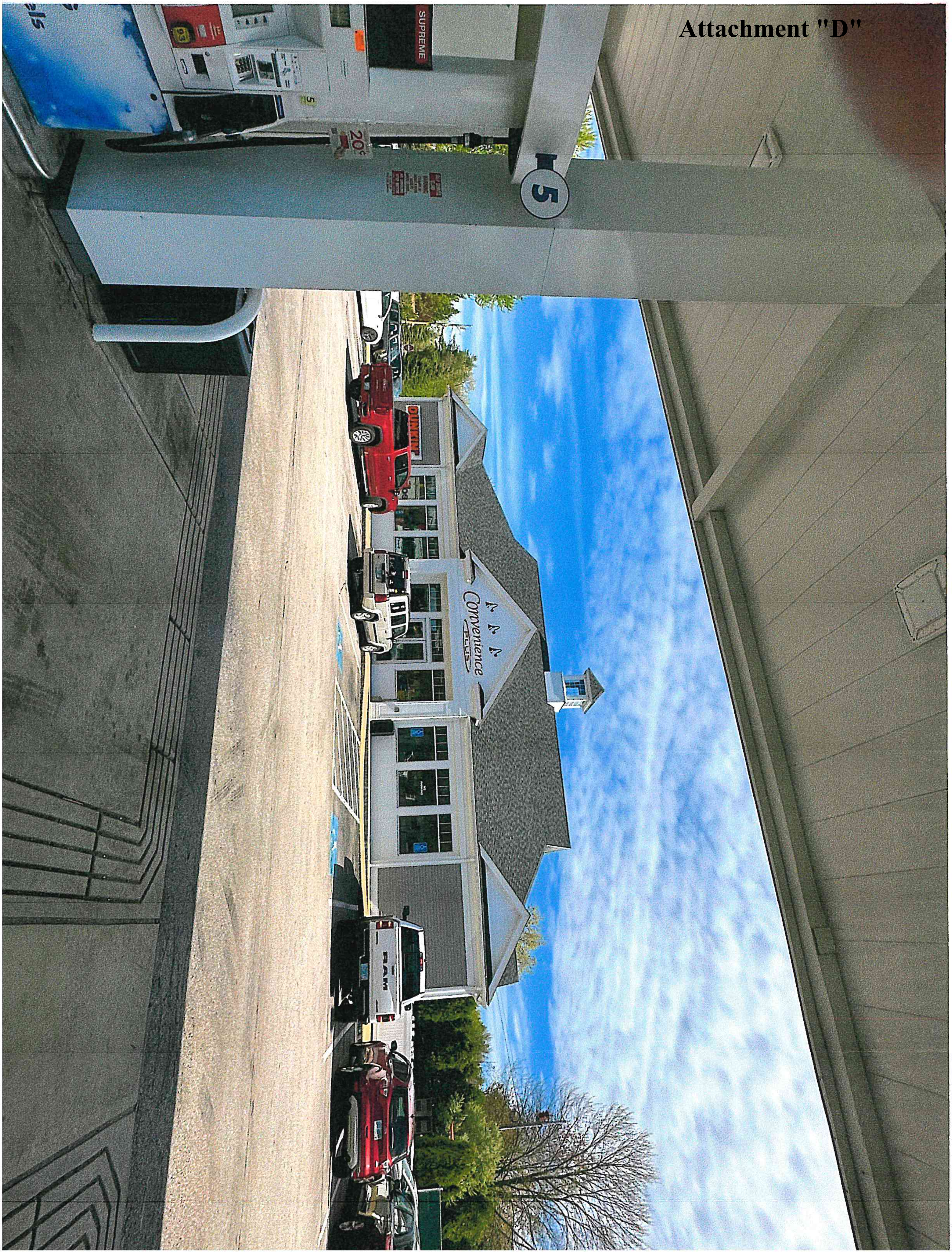
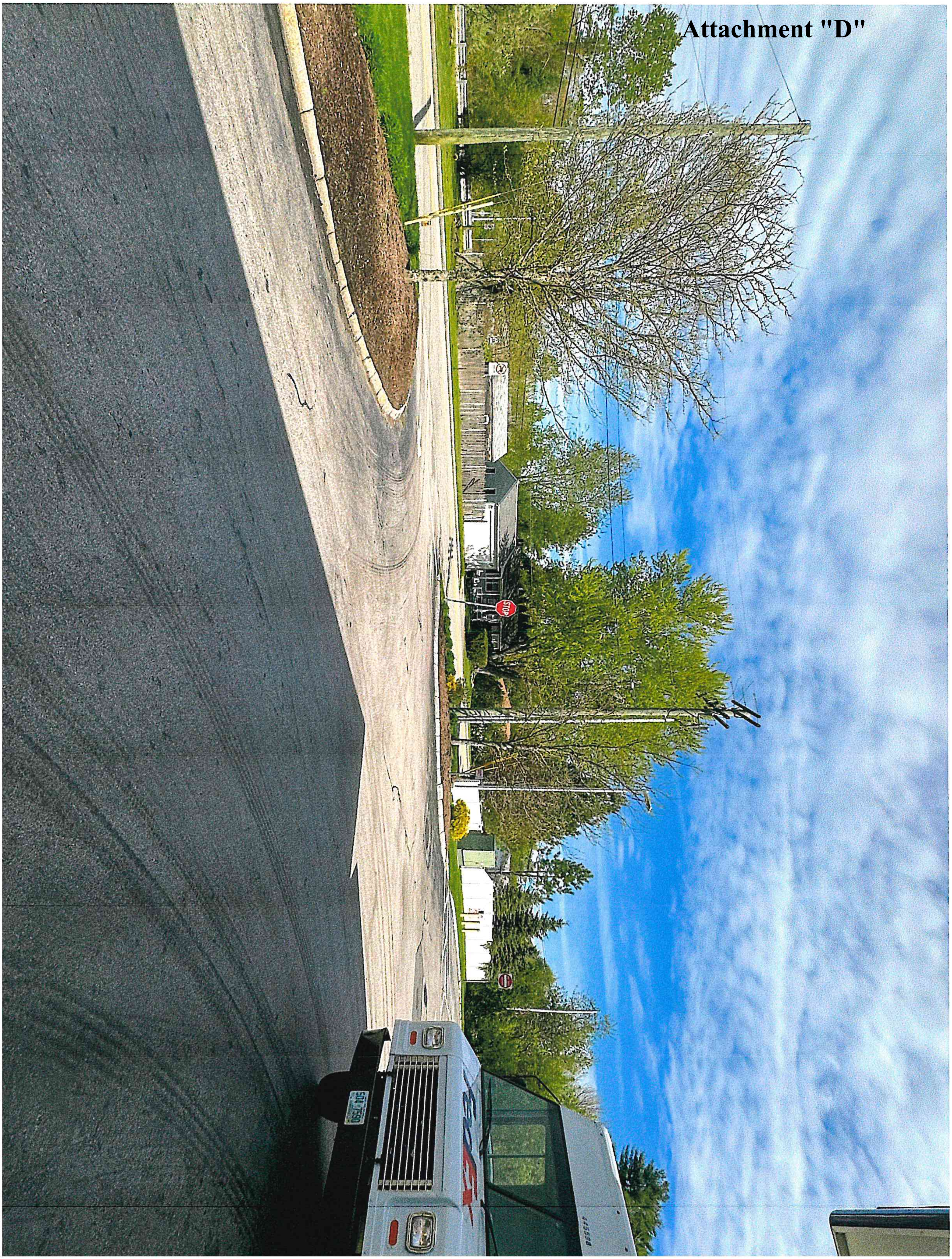


Attachment "D"

Attachment "D"

Attachment "D"



Attachment "E"

TOWN OF HUDSON

Planning Department

12 School Street · Hudson, New Hampshire 03051 · Tel: 603-886-6008 · Fax: 603-594-1142

CAP FEE WORKSHEET - 2023

Date: 11-15-23 Zone # 2 Map/Lot: 182-217-000
77 Central Street

Project Name: Central Gas

Proposed ITE Use #1: Gas Station

Proposed Building Area (square footage): 4,560 S.F.

CAP FEES: (ONE CHECK NEEDED)

1.	**(Bank 09)** **2070-702**	**($18.46 x 800 sqft) Coffee Shop** **Traffic Improve** **(Zone 2)**	 **$ 14,768.00**
2.	**(Bank 09)** **2070-702**	**($3,672 x 10 Pump) Gas Pumps** **Traffic Improve** **(Zone 2)**	 **$ 36,720.00**
		Total CAP Fee	**$ 51,488.00**

Check should be made payable to the Town of Hudson.

Thank you,

Brooke Dubowik

Administrative Aide

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Friday, May 24, 2024 11:50 AM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Friday, May 24, 2024 - 11:50am Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31398 Your Contact Information
First Name Ken
Last Name Dolan
Phone Number (603) 321-8839
Email coach.ken.dolan@gmail.com
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
I am against the gas station on Central Street. And I am against the waiver for second driveway

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Friday, March 15, 2024 12:15 PM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Friday, March 15, 2024 - 12:14pm Form: Contact a Board or Committee Form ID: 42624 Submission ID: 30961 Your Contact Information
First Name Timothy
Last Name Wyatt
Phone Number 603-943-3706
Email timwyattone@gmail.com
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
Hello Planning Board,

I was at the Central Street Gas Station site walk last Saturday and I have a few questions that I am unable to understand from the site plan packet. I appreciate your help to identify where on the site plan I can see the following concerns being addressed:

Where will the Lowell Road right turning lane extension begin and will there be any modification to the waterway overpass on Lowell Road? Will there be a physical barrier on Lowell Road to restrict a left turn into the site?

What accommodations are provided to address possible fuel tank leakage causing contamination of the nearby waterway?

What modifications will be made to the Lowell Road and Central Street intersection to accommodate additional traffic after school and during rush hours? Will Central Street be widened to create a left turning lane into the site?

What is the plan for fuel delivery trucks to maneuver on the site for Central Street egress? What controls will be provided within the site to address traffic congestion resulting from the drive-through, the parking lots and the gas pumps during fuel delivery?

Thank you,
Tim Wyatt
139 Barretts Hill Road

Attachment "F"

Dubowik, Brooke

From: Jake Marynicz <jmarynicz@gmail.com>
Sent: Monday, May 6, 2024 8:21 PM
To: Malley, Tim
Cc: Guessferd, Robert; Dubowik, Brooke
Subject: Central St Gas Station
Attachments: Initial Waiver Request.pdf; Letter.pdf; Recent Waiver Details.pdf

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Dear Planning Board,

My neighbors and I are very concerned about the proposed gas station for 77 Central St and the possible health implications if may have for our neighbors, so much so that we hired an independent Environmental Services consultant to review the plans and they came to the conclusion that 175 households could be at risk for potentially harmful health risks from the proposed gas station.

While both the Town of Hudson and the State of NH does not currently have any regulations for the proximity of new gas stations to residential buildings, (§276-11.1(12)(c)) does reference a 100’ buffer and we believe that it is of the upmost importance that the Planning Board does not provide a waiver to this regulation. I have attached the correspondence from the Environmental Services consultant which include the references to the various University studies regarding the risks of living in close proximity to a gas station.

We also believe that if a waiver was granted that the applicant wouldn’t respect the requirements set forth in a waiver, this is illustrated by the initial waiver request (see attached) stating that, “Only the driveways would be within the 100’ buffer area” but the most recent plans (see point 15 of attached) now state, “driveway, drive aisles & parking” with also discussion of signage falling within the 100’ buffer area. How long before the buildings and gas pumps are also within the 100’ buffer area?

The applicant will claim that the land is impossible to develop without this waiver, but that simply isn’t true, there are multiple use case scenarios for that land that wouldn’t pose a health or environmental impact to the neighborhood.

I sincerely hope the Planning Board will take careful deliberation when considering the granting of waivers for this proposed development, with the understanding the those regulations exist for the purpose of protecting the residents of Hudson.

Sincerely,

Jacob Marynicz

Central St Neighborhood Alliance

Attachment "F"

COMMUNITY & ENVIRONMENTAL DEFENSE SERVICES

Richard D. Klein
24 Greenshire Lane
Owings Mills, Maryland 21117

410-654-3021
Help@ceds.org
ceds.org

March 28, 2024

Jake Marynicz
Hudson Healthy Neighborhoods Alliance
72 Central Street
Hudson, New Hampshire 03051

RE: Potential Health Impacts - Proposed Central Gas SP# 08-23

Dear Mr. Marynicz:

As requested by you and the many other Alliance members, I have reviewed the Central Gas station Site Plan (SP# 08-23). The gas station is proposed for the east side of the intersection of Central Street and Lowell Road. As stated in the February 28, 2024 Staff Report "The applicant proposes building a 10-pump gas station with a 4,560 SF convenience store with drive-thru window." The applicant, Nottingham Square Corporation, has requested Site Plan approval and a waiver of the regulation (§276-11.1(12)(c)) requiring a 100-foot buffer between commercial and residential uses.

As documented by scientific research conducted by Columbia, Johns Hopkins and other universities-institutions, residents of the 175 homes shown in the aerial above that are within 600- to 1,000-feet of the site, may be at risk of adverse health effects due to benzene and other compounds released from the proposed gas station. This research is summarized in this letter.

While I am not an attorney, my layman's read of Hudson Site Plan Review Section 275-6, states that because of the pollution harmful to persons living up to 600-feet away which would be released from the proposed underground fuel storage tank vents and at the pump the following finding required by §275-6H cannot be met:

> "Elimination of undesirable and preventable elements of pollution, such as noise, smoke, soot, particulates or any other discharge, into the environment which might prove harmful to persons, structures or adjacent properties."

Measures that might resolve the health impact are not required by any regulatory agency, including the New Hampshire Department of Environmental Services. This statement is based on emails I exchanged with Nicholas B. Goulas Jr., P.E., Oil Compliance Section Chief, Oil Remediation & Compliance Bureau, NH Department of Environmental Services.

Given that the health impacts of gas station benzene and other air pollutants pose would pose a threat to those living well beyond 100 feet, the waiver of the 100-foot buffer between commercial and residential uses required under §276-11.1(12)(c) should not be approved.

As explained in this letter, denial will not set a precedent precluding new gas stations within Hudson. Instead, future gas stations will be guided to locations where the benefits can be enjoyed without jeopardizing the health of those nearby.

I also suggest that you urge the Hudson Planning Board to request that the Hudson Board of Selectmen amend the Town Code to require a minimum 500-foot public health protection zone between the site boundary of a proposed gas station and residential property boundaries. By establishing the 500-foot setback zone at the site boundary, homes within 600 feet should not be subjected to the harmful effects of benzene and other air pollution emissions from gas station storage tank vents or from pumps.

PROPOSED CENTRAL GAS STATION

I reviewed the following documents as part of this analysis:

- Central Gas Site Plan Staff Report dated February 28, 2024,
- Non-Residential Site Plan Central Gas revised February 14, 2024, and
- Town of Hudson Site Plan Review Regulations.

The Master Plan (Sheet 1 of 20) from the Central Gas Site Plan appears on the next page of this letter. Central Gas is proposed for a 2.9-acre site and would consist of ten pumps, and a 4,560 square foot convenience store with a drive-thru window.

GAS STATIONS & ADVERSE HEALTH EFFECTS
A number of compounds injurious to human health are released from gas stations and other fueling facilities. These compounds include: benzene, toluene, ethyl benzene, and xylene[1] (BTEX). Of these, benzene is the gasoline constituent most harmful to human health. Gas station benzene releases occur at the pump and from the underground storage tank vents like that pictured below.

Since I am not an expert on health effects, the scientific studies and other documents cited here are attached so the reader can confirm the validity of health concerns based on the facts presented in these studies.

Adverse health effects of benzene include cancer, anemia, increased susceptibility to infections, and low birth weight. According to the World Health Organization Guidelines for Indoor Air Quality[2], there is no safe level for benzene. As stated earlier, measures that might resolve the health impact are not required by any regulatory agency, including the New Hampshire Department of Environmental Services. This statement is based on emails I exchanged with Nicholas B. Goulas, P.E., Oil Compliance Section Chief, Oil Remediation & Compliance Bureau, NH Department of Environmental Services.

In 2005, the California Air Resources Board became the first agency in the U.S. to recommend a minimum public health safety zone between new gas stations and

"sensitive land uses such as residences, schools, daycare centers, playgrounds, or medical facilities."

This recommendation appeared in the Air Quality and Land Use Handbook: A Community Health Perspective[3]. The State of California is widely recognized as having some of the most effective air pollution control requirements in the nation. Yet even with California controls a minimum separation between a gas station and homes is still needed to protect public health.

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1 See: https://www.ncbi.nlm.nih.gov/pubmed/26435043
2 See: https://www.ncbi.nlm.nih.gov/books/NBK138708/
3 See: https://files.ceqanet.opr.ca.gov/221458-6/attachment/UNr-g159CW-r0G4DR8q6daNdAKT3RJTd8gGQCfz4wqFfl-eNdZNQEqjf8tfls1x6Gsae7YqpXwtFIZBd0

The U.S. Environmental Protection Agency echoed concerns about the health risk associated with gas station emissions in their School Siting Guidelines[4]. The USEPA recommended screening - but not excluding - school sites for potential health risk when located within 1,000 feet of a gas station.

The safety zone distances were prompted by the large and growing body of research showing that adverse health effects are found to extend further and further from gas stations with each new study.

A seminal 2015 study, Hydrocarbon Release During Fuel Storage and Transfer at Gas Stations: Environmental and Health Effects[5], contained the following summary regarding the health implications of living near a gas station:

> *"Health effects of living near gas stations are not well understood. Adverse health impacts may be expected to be higher in metropolitan areas that are densely populated. Particularly affected are residents nearby gas stations who spend significant amounts of time at home as compared to those who leave their home for work because of the longer period of exposure. Similarly affected are individuals who spend time close to a gas station, e.g., in close by businesses or in the gas station itself. Of particular concern are children who, for example, live nearby, play nearby, or attend nearby schools, because children are more vulnerable to hydrocarbon exposure."*

A 2019 study, Vent pipe emissions from storage tanks at gas stations: Implications for setback distances[6], of U.S. gas stations found that benzene emissions from underground gasoline storage tank vents were sufficiently high to constitute a health concern at a distance of at least 524-feet. Also, the researchers noted:

> "*…emissions were 10 times higher than estimates used in setback regulations* [like that in the California handbook] *used to determine how close schools, playgrounds, and parks can be situated to the facilities* [gas stations]."

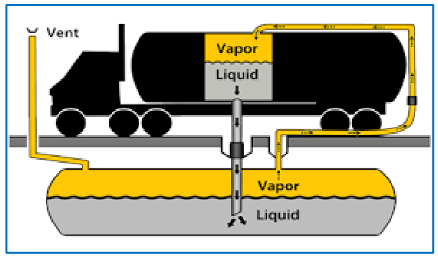
Prior to the 2019 study it was thought that most of the benzene was released at the pump during fueling.

Control Measures Will Not Resolve Benzene Health Threat

The two most common control measures for gas stations are Stage I[7] and Stage II Vapor Recovery[8].

Stage I regulations require that the release of benzene and other compounds be controlled while underground storage tanks are being filled.

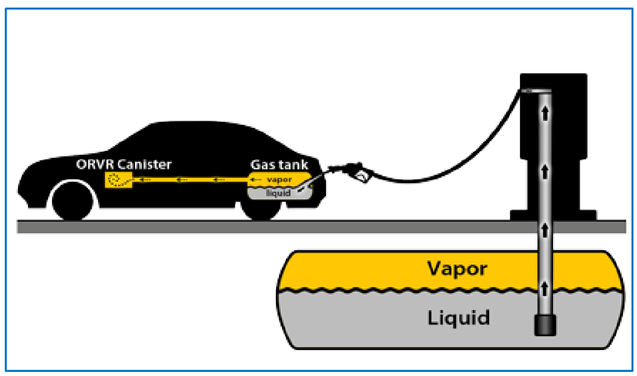
[4] See: https://www.epa.gov/sites/production/files/2015-06/documents/school_siting_guidelines-2.pdf
[5] See: https://www.ncbi.nlm.nih.gov/pubmed/26435043
[6] See: https://www.sciencedirect.com/science/article/pii/S0048969718337549
[7] See: https://www.pca.state.mn.us/sites/default/files/t-u1-13.pdf
[8] See: https://www3.epa.gov/region1/airquality/gas.html



As shown in the figure to the right, which is from the 2019 study[9], Stage I measures minimize the release of vapors from an underground tank. The vapors are captured and pumped back into the truck storage reservoir. However, federal regulations and those of most states **DO NOT** require control of vapor (benzene) release during the 99% of time when storage tanks are not being filled.

A decade ago, most gas pump nozzles were designed to capture vapors released during refueling. The vapors were then sent to the 10,000- to 20,000-gallon underground tanks where gasoline is stored. These Stage II vapor recovery systems were phased out beginning in 2012 as a result of the widespread use of Onboard Refueling Vapor Recovery (ORVR) systems.

As the name implies, Onboard Refueling Vapor Recovery systems are built into new cars. The system captures vapors during refueling which are then stored in canisters within the vehicle. A 2020 study, Gasoline Vapor Emissions During Vehicle Refueling Events in a Vehicle Fleet Saturated With Onboard Refueling Vapor Recovery Systems: Need for an Exposure Assessment[10], by Dr. Markus Hilpert and others examined the effectiveness of Onboard Refueling Vapor Recovery systems, like that shown in the figure to the left from the 2020 study. The researchers found that 88% of vehicles monitored released vapors during refueling despite the presence of Onboard Refueling Vapor Recovery systems. This finding raised serious questions regarding the public health protection effectiveness of ORVR systems.



On the next page are photos of measures attached to underground fuel storage tank vents that can remove benzene and other pollutant from vented vapors. I specifically asked if these or equally effective measures would be required to control benzene or other pollutant releases from underground storage tank vents during the 99% of time when the tanks are not being filled. These measures are not required by any regulatory agency, including the New Hampshire Department of Environmental Services. This is based on emails I exchanged with Nicholas B. Goulas, P.E., Oil Compliance Section Chief, Oil Remediation & Compliance Bureau, NH Department of Environmental Services.

[9] See: https://www.sciencedirect.com/science/article/pii/S0048969718337549
[10] See: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7020915/

The 2019 study cited previously in this letter addressed the release of benzene from underground gasoline storage tank vents and documented that the amount of benzene released was substantial and could be detected at a distance of up to 524 feet.

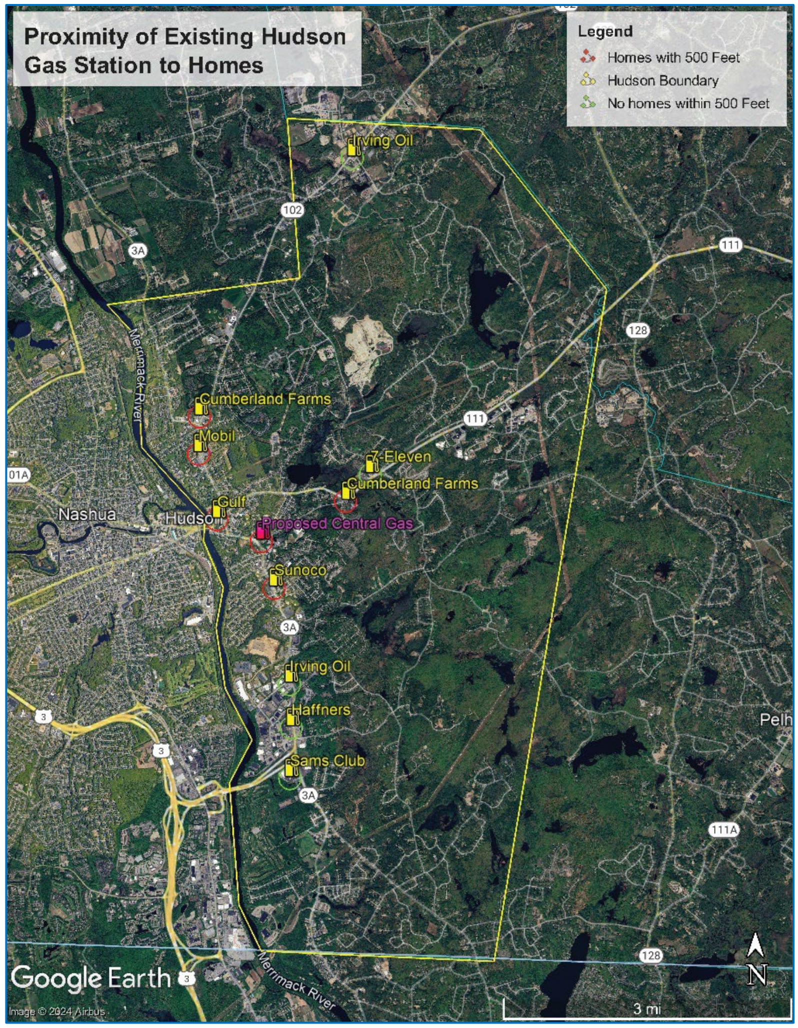
It is for the reasons outlined above that a gas station should not be located within at least 500-feet of homes. This setback distance should be from the outer boundary of a proposed gas station and the nearest residential property boundary. Basing the public health separation distances on a gas station site boundary rather than the proposed location of gas pumps or storage tank vents is necessary due to the possibility of future changes that could move these benzene sources closer to homes within a site boundary.

500-FOOT HEALTH PROTECTION ZONE & NEW HUDSON GAS STATIONS

Occasionally, a concern will arise that denying approval for a proposed gas station because the site is within 500 feet of homes will preclude any new fuel dispensing facility within a jurisdiction like the Town of Hudson. Of course, the U.S. is headed towards phasing out gasoline powered vehicles so the need for new gas stations should decline in the coming decade or two.

For reasons explained in the video at the following address, new gas stations tend to locate near existing ones: https://www.youtube.com/watch?v=u4cKzGj58q4. As a result, applying a 500-

foot setback to existing gas stations is a valuable method for assessing if the public health safety zone will unduly restrict new gas stations in a jurisdiction.



The aerial to the right shows the location of 11 existing gas stations in the Town of Hudson. Gas stations where the gas pump symbol is circled with **red** are within 500 feet of multiple homes. Gas stations with **green** circles are more than 500 feet from multiple home.

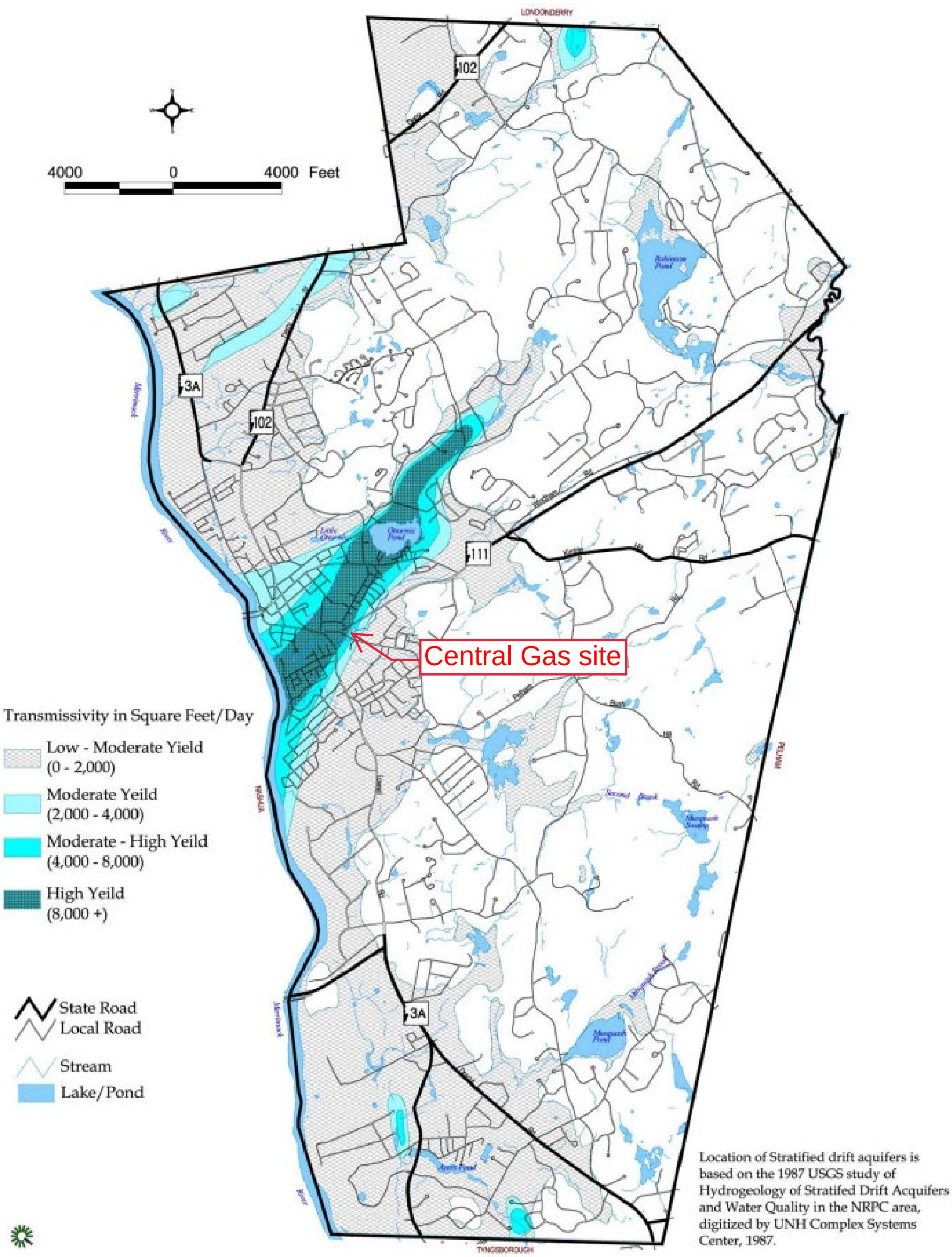
Of the 11 stations, 5 (45%) are more than 500 feet from the nearest cluster of homes. Given that nearly half of existing stations would easily meet the 500-foot setback, it is unlikely that denying a Site Plan approval for the proposed Central Gas facility would set a precedent precluding new gas stations in the Town of Hudson. Instead, new stations would be guided to sites where the benefits are gained without jeopardizing public health.

AQUIFER CONTAMINATION POTENTIAL

On the next page is Map III-8 Aquifers, from the Town of Hudson Master Plan. Note that the Central Gas site is located partially within the area underlain by the only High Yield aquifer in the Town of Hudson. The site also lies in the Moderate-High Yield and Moderate Yield aquifer areas. According to the NHDES OneStop Data Mapper, it is a GA2 aquifer.

The table on page 3, of The DES Guide to Groundwater Protection, lists underground storage tanks, such as those at gas stations, as a potential groundwater contamination source. While it is thought that current underground tank design, installation and monitoring has substantially reduced the leak potential, these measures are by no means fool proof. I suspect this is the reason why New Hampshire Code 602.11 calls for a 500-foot separation between “All gasoline underground storage tank systems” and “public water supply wells.” While a public water supply well does not exist within 500 feet of the Central Gas site, this regulation indicates the need for caution when locating gas stations near important water supply sources, such as the aquifer depicted in Map III-8.

Map III-8. Aquifers



Furthermore, underground storage tank leakage is not the only source of aquifer contamination at gas stations. A 2014 Johns Hopkins University study (published after the Guide was written in 2008) shows that gas spilled at pumps can percolate through the concrete pads present at many pumps and possibly reach underlying groundwaters though the quantity is small compared to tank leakage. I do not believe any measures are required to address this issue. This is yet another reason why approval should not be granted for the Central Gas Site Plan.

SITE PLAN APPROVAL CRITERIA & HEALTH & AQUIFER IMPACTS

Hudson Site Plan Review Section 275-6, sets forth General Requirement regarding "In the review of any nonresidential SITE PLAN conducted under this regulation, the PLANNING BOARD shall require that adequate provisions be made by the OWNER or his/her/its authorized agent for the following:"

Of course, the Central Gas Site Plan is Non-Residential. Of requirements A to X, the potential public health and aquifer impacts documented in these comments shows that the following cannot be met:

A. The safe and attractive DEVELOPMENT of the site and to guard against such conditions as would involve danger or injury to health or safety, and no significant diminution in value of surrounding properties would be suffered.

F. Stormwater drainage and groundwater recharge.

G. Water supply, wastewater disposal and solid waste disposal.

H. Elimination of undesirable and preventable elements of pollution, such as noise, smoke, soot, particulates or any other discharge, into the environment which might prove harmful to persons, structures or adjacent properties.

My layman's (non-lawyer) read of the above regulations indicate that due to the adverse health effects of benzene released from gas stations (as documented in this letter) and the potential for aquifer impact, the proposed Central Gas Site Plan fails to meet the four require findings highlighted yellow above. Therefore, the Hudson Planning Board is obligated to deny the Site Plan approval and the waiver requested by the applicant.

I can be reached at 410-654-3021 or Rklein@ceds.org if you have any questions.

Sincerely,

Richard D. Klein

Attachment "F"

2015 Study
Hydrocarbon Release During Fuel Storage and Transfer at Gas Stations: Environmental and Health Effects

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Curr Envir Health Rpt (2015) 2:412–422
DOI 10.1007/s40572-015-0074-8

Attachment "F"

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Hydrocarbon Release During Fuel Storage and Transfer at Gas Stations: Environmental and Health Effects

Markus Hilpert[1] · **Bernat Adria Mora**[1] · **Jian Ni**[2] · **Ana M. Rule**[1] · **Keeve E. Nachman**[1]

Published online: 5 October 2015

Abstract At gas stations, fuel is stored and transferred between tanker trucks, storage tanks, and vehicle tanks. During both storage and transfer, a small fraction of unburned fuel is typically released to the environment unless pollution prevention technology is used. While the fraction may be small, the cumulative release can be substantial because of the large quantities of fuel sold. The cumulative release of unburned fuel is a public health concern because gas stations are widely distributed in residential areas and because fuel contains toxic and carcinogenic chemicals. We review the pathways through which gasoline is chronically released to atmospheric, aqueous, and subsurface environments, and how these releases may adversely affect human health. Adoption of suitable pollution prevention technology should not only be based on equipment and maintenance cost but also on energy- and health care-saving benefits.

Keywords Gas stations · Vapor emissions · Fuel spills · Adverse health effects · Pollution prevention

Introduction

The primary function of gas stations is to provide gasoline and diesel fuel to customers, who refill vehicle tanks and canisters. Operating a gas station requires receiving and storing a sufficient amount of fuel in storage tanks and then dispensing the fuel to customers. During delivery, storage, and dispensing of fuel at gas stations, unburned fuel can be released to the environment in either liquid or vapor form. Fuel is a complex mixture of chemicals, several of them toxic and carcinogenic [1]. Of these chemicals, the health consequences of chronic benzene exposure are best understood. Occupational studies have linked benzene exposures to numerous blood cancers, including acute myeloid leukemia and acute non-lymphocytic leukemia [2]. Concerns have been raised that gasoline vapor exposures incurred by gas station attendants [3] and tanker truck drivers [4] may result in health risks.

The potential for fuel released to the environment at gas stations, in the form of liquid spills or vapor losses, to elicit adverse health outcomes could be substantial due to the widespread distribution of gas stations across communities and the intensive usage of vehicle fuel in industrialized nations. For example, the USA consumed about 137 billion gallons of gasoline, or about 430 gallons per US citizen, in 2014 [5]. If only a small fraction of this gasoline was to be released to the environment in the form of unburned fuel, for instance 0.1 %, then about 1.6 L of gasoline would be released per capita per year in the USA. In Canada, a study estimated that evaporative losses at gas stations in 2009 amounted to 58,300,000 L [6]. With a population of about 34 million, we estimated that about 1.7 L of gasoline was released per capita per year in Canada from evaporative losses, without counting the liquid spills. While personal intake of this quantity of gasoline would result in serious adverse health effects, environmental dilution can decrease personal exposure. An overarching question is under which conditions dilution in the aqueous and atmospheric environments can limit personal exposures to acceptable levels. For example, cumulative adverse health effects could be more pronounced in metropolitan areas where more people

This article is part of the Topical Collection on *Air Pollution and Health*

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are exposed and where the density of gas stations is larger than in rural areas.

Engineers and regulators have paid a lot of attention to leaking underground storage tanks (LUSTs) and leaky piping between storage tanks and gasoline-dispensing stations, which can result in catastrophic fuel release to the subsurface [7]. For instance, double-walled tanks have become standard in order to minimize accidental release of liquid hydrocarbon. Technologies that prevent pollution due to non-catastrophic and unreported releases of hydrocarbon that occur during fuel storage and transfer (hereafter referred to as "chronic releases"), however, have not been uniformly implemented within the developed world. The state of California in the USA has the strictest policies to minimize chronic releases, either in liquid or in vapor form. Other US states and industrialized nations, however, have not uniformly adopted California's standards, potentially because comprehensive economic and public health analyses to inform policy making are not available. This paper focuses on chronic hydrocarbon releases at gas stations (including both liquid spills and vapor losses), their contributions to human exposures and potential health risks, and factors that influence the adoption of suitable pollution prevention technology.

Chemical Composition of Fuel

Fuels have historically contained significant fractions of harmful chemicals, some of which have been documented as contributing to morbidity and mortality in exposed persons. Crude oil, from which fuels have historically been refined, already contains toxic chemicals such as benzene [8]. Fuel additives including anti-knocking agents and oxygenates have historically also been a health concern [9]. Fuel composition has changed over time, primarily due to environmental and health concerns [9]. Fuel composition also depends on geographic location and fuel type (e.g., conventional versus reformulated gasoline) [10]. In the 1920s, lead was added to gasoline as an anti-knocking agent to replace added benzene because of its carcinogenicity [11]. Due to the massive release of lead to the environment and its neurotoxicity [12], lead was replaced in the 1970s by less toxic anti-knocking agents including methyl tert-butyl ether (MTBE) [13]. To reduce formation of ground-level ozone and associated adverse respiratory health effects [14], cleaner burning of fuel was sought in the 1990s by adding oxygenates to gasoline. This was accomplished by increasing the concentrations of MTBE, which acts as an oxygenate [9]. However, MTBE accidentally released to the subsurface [15] contaminated downstream drinking water wells relatively quickly, moving almost with the speed of groundwater, because MTBE is hydrophilic and poorly biodegradable [16]. MTBE was later on identified as a potential human carcinogen [16]. In the USA, MTBE was therefore phased out in the 1990s; at the same time, refineries began supplementing fuel with ethanol as an oxygenate [17].

In current gasoline formulations, benzene, toluene, ethylbenzene, and xylene (BTEX) and particularly benzene are the most studied chemicals and are currently believed to be of greatest health concern [18]. Table 1 shows that fuels have historically contained large fractions of toxic and carcinogenic chemicals. In many countries, lead and MTBE are no longer used. Benzene levels in gasoline are currently much lower in most countries (e.g., on average 0.62 % by volume in the USA), though the chronic health effects of benzene and other BTEX chemicals at relevant exposure levels are not well understood.

Chronic Release and Environmental Transport of Contaminants from Fuel

At gas stations, fuel can be released in both liquid and vapor phases during delivery, storage, and dispensing. Direct vapor release is usually associated with atmospheric pollution, while liquid spillage is commonly associated with soil and groundwater contamination. However, spilled liquid fuel also evaporates into the atmosphere. Hypothetically, hydrocarbon vapors can also condense back into liquid form; however, this appears to be unlikely due to quick dilution in a typically turbulent atmosphere. Figure 1 depicts how releases of unburned fuel contaminate the atmospheric, subsurface, and surface water environments (omitting LUST and leaky piping as well as marine gas stations which may release fuel directly to surface water).

Liquid Fuel Spills

Liquid fuel spills at the nozzle have received less attention than liquid releases due to LUSTs. These fuel spills occur when the dispensing nozzle is moved from the dispensing station to the vehicle tank and vice versa, when the automatic shutoff valve fails, due to spitback from the vehicle tank after the shutoff has been activated, and when the customer tops off the tank.

Table 1 Historical content of non-negligible amounts of toxic and carcinogenic chemicals in fuel

Chemical of concern	Fraction	Health effects
Benzene	Up to 5 % [75]	Carcinogenic [2]
Lead	Up to 2 g per gallon [76]	Central nervous system [12]
MTBE	Up to 15 % [77]	Potential human carcinogen [78]

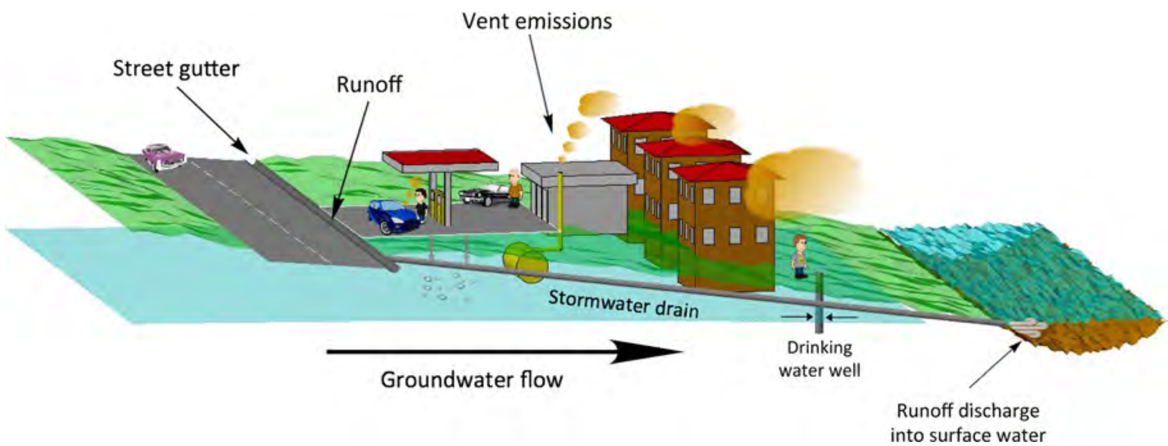

Fig. 1 Gas stations are embedded into the natural environment and can consequently release pollutants to the atmosphere, the subsurface including soil and groundwater, and surface water

In a study quantifying fuel spill frequencies and amounts at gas stations in California, about 6 L of gasoline was spilled per 16,200 gallons of gasoline dispensed at gas stations without stage II vapor recovery compared to 3.6 L at gas stations per 14,043 gallons of gasoline dispensed at gas stations with stage II vapor recovery (at the nozzle) [19]. This would mean that about 0.007 and 0.01 % of dispensed gasoline are spilled in liquid form during vehicle refueling at gas station with and without stage II recovery (numbers calculated using the assumed fuel density of 6.2 pounds/gallon). On the other hand, a study sponsored by the American Petroleum Institute found that more spills occurred at gas stations with stage II recovery [20].

We have recently performed laboratory experiments to examine the fate of liquid spill droplets. Following our previous protocol [21•], we spilled fuel droplets onto small concrete samples and measured the mass added to the concrete as a function of time. This added mass is the sum of the masses of the sessile fuel droplet and the infiltrated fuel. Figure 2 shows results for diesel and gasoline. After a certain period of time, the sessile droplet vanishes and the measured mass levels off. The remaining mass represents the infiltrated portion. The evaporated mass can be obtained by subtracting the infiltrated mass from the initial droplet mass m_0. Evaporation is greater for gasoline, while infiltration is greater for diesel spills. This is because gasoline is more volatile than diesel. Diesel has therefore a higher potential for soil contamination because of the higher infiltrated mass.

Spilled fuel may move downward in liquid or vapor phase and potentially reach the groundwater table. The physical mechanisms that govern subsurface movement of spilled fuel are the same as for fuel released due to LUST, except that spilled fuel must first penetrate relatively impermeable pavement underneath fuel-dispensing stations. Gasoline and diesel will not penetrate the groundwater table as a liquid, because they have densities lower than that of water. Released fuel may also evaporate within the sediment, and a portion of it will move downward as a vapor and potentially reach the groundwater table [22]. Whether the fuel reaches groundwater in liquid or vapor form, the fuel will then partition into groundwater and become a dissolved chemical that is carried away by molecular diffusion and groundwater flow and associated hydrodynamic dispersion [23]. Therefore, the spills can contaminate downstream drinking water wells [24]. Biodegradation can decrease contaminant concentrations significantly; however, its efficiency depends on many factors including the chemical composition of the fuel and the presence of suitable microbial species that can metabolize a given contaminant, bioavailability, and electron acceptor availability [25]. Partitioning of the contaminant into other phases will cause

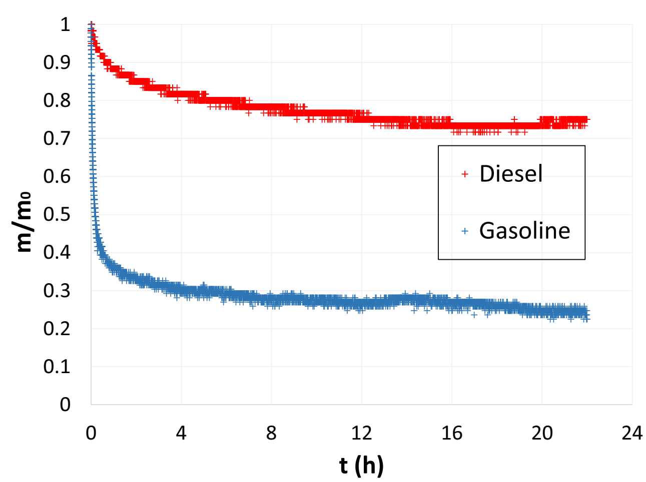

Fig. 2 Results from laboratory experiments, in which we spilled a mass m_0=1 g of diesel or gasoline onto concrete samples. The measured mass m represents the masses of the sessile droplet and infiltrated liquid

retarded transport of the contaminant within groundwater. For instance, hydrophobic contaminants such as benzene tend to sorb to the sediment. For this reason, large-scale contamination of aquifers and associated adverse health effects due to the ingestion of contaminated drinking water from these aquifers are often considered a lesser concern for hydrophobic contaminants [16].

Stocking et al. [26] evaluated the potential of groundwater contamination due to small one-time releases of liquid gasoline. In a case study, they assumed a spill volume much bigger than the ones typically measured by the study of gas stations in California [19], i.e., 0.5 L, and they concluded the risk to groundwater to be small. This analysis, however, did not include consideration of a key mechanism for fuel spillage; namely, that much smaller droplets are typically released during vehicle refueling [19]. To address this question, Hilpert and Breysse [21•] calculated cumulative spill volumes due to repeated small spillages that occur at gasoline-dispensing facilities and estimated that a gas station selling about 400,000 L of gasoline per month would spill at least 150 L each year. They also developed a model that shows that the fraction of spilled gasoline that infiltrates into the pavement increases as the droplet size decreases. Therefore, repeated small spills could be of greater concern for groundwater contamination than an instantaneous release of the cumulative spill volume; thus, a risk to groundwater may not be as small as previously estimated.

Laboratory experiments and modeling have shown that gasoline from small-volume spills can infiltrate into the concrete that usually covers the ground underneath gasoline-dispensing stations—despite the low permeability of concrete and the high vapor pressure of gasoline [21•]. It is unlikely that liquid fuel fully penetrates a concrete slab to contaminate the underlying natural subsurface due to the low permeability of concrete [27], although preferential pathways for fluid flow such as cracks and faulty joints between concrete slabs can allow for such liquid penetration. It has been hypothesized that evaporation of infiltrated gasoline and subsequent downward migration of the vapor through the concrete may lead to contamination of underlying sediment and groundwater [21•]. Consistent with these two proposed pathways of subsurface contamination, soil/sediment underneath concrete pads of a gas station in Maryland was contaminated by diesel oil and gasoline (leaky piping could have also contributed to the contamination) [28].

Runoff water that flows over pavement can also get contaminated with hydrocarbons spilled onto the pavement [29–31], and such contamination has specifically been linked to gas stations [32–34]. If a spill occurs while runoff occurs, the hydrocarbon can be expected to float on top of the water sheet, because gasoline, diesel oil, and lubricants are typically less dense than water (light non-aqueous phase liquids or LNAPLs). While runoff water is not directly ingested, it is funneled into the stormwater drainage system, and may be released to natural water bodies, often without treatment. Whereas volatilization decreases contaminant levels in the stormwater within hours depending on the exact environmental conditions [35], and biodegradation will further decrease levels, significantly contaminated stormwater might be released to natural water bodies if they are close by. Finally, fuel spilled at marine gas stations may directly enter natural water bodies.

Vapor Fuel Releases

Fuel evaporative losses have received more attention than liquid fuel spills (even though they are related) [6, 36]. These losses are related to the fact that the headspace above liquid fuel in vehicle and storage tanks tends to approach thermodynamic equilibrium with the liquid. Consequently, almost saturated gasoline vapors can be released to the atmosphere when tanks are refueled, unless a suitable vapor recovery system is in place. Since saturated gasoline vapors have a density that is three to four times larger than the one of air, i.e., 4 kg/m^3, and the density of liquid gasoline is about 720 kg/m^3 [37], about 0.5 % of liquid gasoline dispensed to a tank is released to the atmosphere if the entire headspace is in equilibrium with the liquid fuel. This is true for any type of tank, whether it is a vehicle tank, a canister, an underground storage tank (UST), or an above-storage tank. The percentage loss is less if a tank received clean air relatively recently, e.g., when the fuel level in a storage tank drops because of gasoline-fuel dispensing.

It is important to note that vapor recovery at the nozzle can cause vapor releases at the storage tank, because vapors recovered at the nozzle are typically directed into the storage tank. The storage tank, in turn, can “breathe” and potentially release recovered vapors immediately or at a later time. A tank sucks in relatively uncontaminated air as the liquid fuel level drops in the tank due to vehicle refueling, and it releases vapors through the vent pipe into the atmosphere if the gas pressure increases and exceeds the cracking pressure of the pressure/vacuum valve, when fuel evaporates into unequilibrated gas in the headspace.

As discussed in the “Liquid Fuel Spills” section above, we note that liquid spills also contribute to air pollution because spilled droplets form sessile droplets on pavement that can then evaporate into the atmosphere. On concrete, most of spilled gasoline droplets evaporate into the atmosphere (Fig. 2). This, however, does not mean that the small fraction that infiltrates into the concrete is not of concern.

Exposure and Risks to Human Populations

Gas stations exist as part of the built environment and are widely distributed across communities. As a result, they may be surrounded by residential dwellings, businesses, and other buildings such as schools. Operation of gas stations may thus create opportunities for a variety of human populations to be exposed to vapors during station tank filling and vehicle refueling. These human populations can be broadly grouped into three groups: populations exposed occupationally as a result of employment in various capacities at the service station; those exposed as customers engaging in vehicle refueling; and those passively exposed either by residing, attending school, or working near the refueling station. The exposures to benzene and other components of refueling vapors and spills experienced by these populations vary based on a number of factors, including the size and capacity of the refueling station, spatial variation in pollutant concentrations in ambient air, climate, meteorological conditions, time spent at varying locations of the service station, changing on-site activity patterns, physiological characteristics, and the use of vapor recovery and other pollution prevention technologies.

Employees at service stations (such as pump attendants, on-site mechanics, and garage workers) are among those with greatest exposure to benzene originating from gas stations [3]. These receptors spend the most time on site (potentially reflecting approximately 40 h per week, for decades) and intermittently spend time where vapors from the pump are at their highest concentrations, with benzene concentrations measuring between 30 and 230 ppb in the breathing zone [38–40]. Gas station patrons can also be exposed to vapors when refueling. Compared to station employees, their exposures are brief and transient. A Finnish study reported a median time spent refueling of approximately 1 min, whereas 3 min was the median duration in the USA [41, 42]. The same US study reported an average benzene personal exposure concentration at the pump of 910 ppb, with the strongest predictors of benzene levels being fuel octane grade, duration of exposure, and season [42].

Those occupying residences, businesses, and other structures neighboring gas stations can also be exposed to fuel vapors originating in the gas station, though typically at lower concentrations than those measured at the pump. While vapor concentrations will drop as the distance from the service station increases, exhaust fumes from waiting customers and fuel delivery trucks can also contribute to vapors in proximity to gas stations. A small number of studies have examined benzene concentrations at the fenceline of the service station and beyond. A study published by the Canadian petroleum industry found average benzene concentrations of 146 and 461 ppb at the gas station property boundary in summer and winter, respectively [43]. A South Korean study examined outdoor and indoor benzene concentrations at numerous residences within 30 m and between 60 and 100 m of gas stations and found median outdoor benzene concentrations of 9.9 and 6.0 $\mu g/m^3$ (about 3.1 and 1.9 ppb), respectively. Median indoor concentrations at these locations were higher, reaching 13.1 and 16.5 $\mu g/m^3$ (about 4.1 and 5.2 ppb), respectively [44]. Another study found median ambient benzene levels of 1.9 ppb in houses both <50 and >100 m from a service station [45]. Yet, another study [46] found that benzene and other gasoline vapor releases from service stations can be discerned from traffic emissions as far as 75 m from service stations and that the contribution of service stations to ambient benzene is less important in areas of high traffic density. This is because vehicle exhaust is usually the most abundant volatile organic compound (VOC) in urban areas, often followed by gasoline vapor emissions from fuel handling and vehicle operation [47].

Beyond contact with surface-level gasoline vapors, fuel releases may result in other exposure pathways. Soil and groundwater contamination is common at gas stations. Drinking water wells proximate to gas stations, which in rural areas are often the only drinking water source, can become contaminated, potentially exposing well users to benzene and other chemicals [48, 49]. In addition, runoff from rain and other weather events can carry spilled hydrocarbons, which can contaminate surface waters; those using surface waters, either recreationally or for other purposes, may be exposed to these contaminants through dermal contact or incidental ingestion.

In the USA, the Environmental Protection Agency (EPA) regulates releases of benzene under the Clean Air Act as a hazardous air pollutant, and benzene is listed as number 6 on the 2005 priority list of hazardous substances under the Comprehensive Environmental Response, Compensation, and Liability Act and any release greater than 10 pounds triggers a reporting requirement. Different quantitative toxicity metrics exist for benzene inhalation. The EPA Integrated Risk Information System (IRIS) has published a reference concentration of 0.03 mg/m^3 (about 9.4 ppb), corresponding to decreased lymphocyte counts [50], whereas the NIOSH recommended exposure limit (REL) is a time-weighted average concentration (for up to a 10-hour workday during a 40-hour workweek) of 0.319 mg/m^3 (about 100 ppb) [51].

While research attention has been paid to measurement of gasoline vapor constituent concentrations in air at and near service stations, less is known about the health consequences faced by those that are exposed to gasoline vapors. Of the limited literature examining these exposures, service station workers have received the greatest attention, and exposure is often assessed as a function of job title, rather than specific measurements of vapor constituent concentrations. An older study looking broadly at leukemia incidence in Portland, Oregon, found that gas station workers were at significantly increased risk for lymphocytic leukemia [52]. A proportionate mortality ratio analysis of all deaths recorded in New Hampshire among white men from 1975 to 1985 found elevated leukemia mortality in service station workers and auto mechanics [53]. The type of leukemia was not specified. An Italian occupational cohort study of refilling attendants that examined risks among workers at smaller gas stations reported non-significant increases in mortality for non-Hodgkin's lymphoma and significantly elevated mortality for esophageal cancer in men, as well as increased brain cancer mortality in both sexes [54]. A different cohort of 19,000 service station workers in Denmark, Norway, Sweden, and Finland examined an array of cancer end points and found increased incidence for multiple sites (nasal, kidney, pharyngeal, laryngeal, and lung) among workers estimated to be occupationally exposed to benzene in the range of 0.5–1 μg/m^3 (0.16 - 0.31 ppb). Non-significant increased incidence was found for acute myeloid leukemia in men and for leukemia different from acute myeloid leukemia and chronic lymphocytic leukemia in women [55]. A case–control study of multiple occupations including subjects from the USA and Canada found significant increases in rates of total leukemia and acute myeloid leukemia but not acute lymphocytic leukemia in gas station attendants [56]. A 2015 review of studies examining potential relationships between benzene exposures and hematopoietic and lymphatic cancers among vehicle mechanics yielded inconclusive results, although it suggested that if an effect was to exist, it would be small and difficult to rigorously ascertain with existing epidemiologic methods [57].

The health consequences of nearby residents of gas stations have not been studied. However, it is known that contaminated groundwater can affect large numbers of people if the groundwater is used as drinking water, as was the case in Camp Lejeune (North Carolina, USA) where thousands were exposed to a range of chemicals including gasoline released from LUSTs [58]. A study of Pennsylvania residents residing in close proximity to a large gasoline spill from a LUST found evidence of increased leukemia risks [49, 59••]. The health consequences of chronic fuel releases at gas stations that can, for example, occur due to ingestion of contaminated groundwater, fuel vapor intrusion from contaminated soil and groundwater into dwellings [60], and atmospheric vapor releases during fuel transfer and storage have not been studied. While limited measurements of ambient concentrations of vapor constituents in communities were identified, literature searches did not identify studies of the health consequences of inhalation exposures to gasoline vapors among community residents [61].

Pollution Prevention

Pollution prevention technologies have been developed that can efficiently reduce the releases of unburned fuel to the environment that routinely occur during fuel storage and transfer (see Fig. 3):

1. Stage I vapor recovery collects vapors that would be expelled from USTs during fuel delivery [62]. Without stage I vapor recovery, about 80 kg of gasoline vapor would be released from a 40 m^3 UST if one assumes a saturated vapor density of 4 kg/m^3 [37] and vapors in the headspace

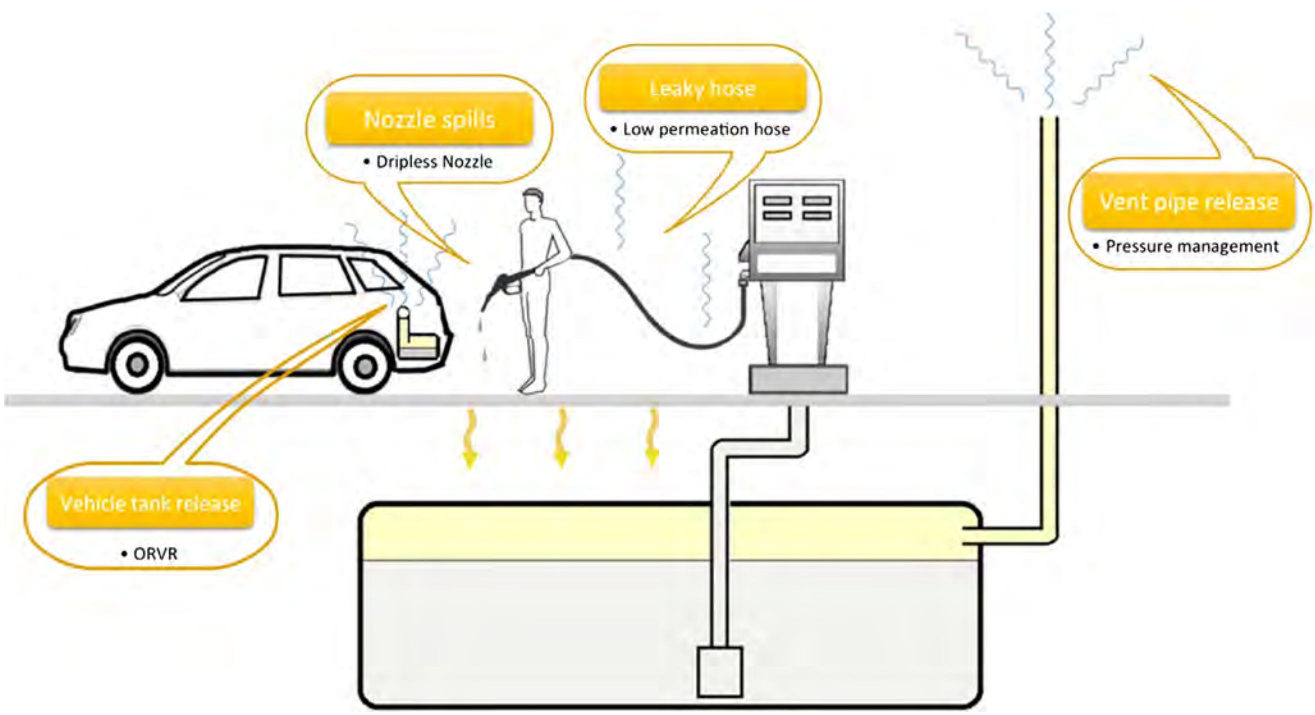

Fig. 3 There are several sources of chronic release of unburned fuel at gas stations that occur due to fuel storage and dispensing: vapor release through the vent pipe of the storage tank, vapor release from the vehicle tank during refueling, leaky dispensing hoses, liquid spills during vehicle refueling, and vapor emissions through evaporation of this spilled fuel. As indicated, suitable pollution prevention technology can minimize the releases. Onboard refueling vapor recovery (ORVR)

to be at half saturation. Stage I vapor recovery can thus prevent substantial fuel vapor releases that would occur within a short period of time. Such releases might expose tanker truck drivers and persons in the proximity of a gas station to significant doses of fuel vapors. Stage I vapor recovery is accomplished by establishing a closed loop between the UST and the tanker truck. Through a fuel delivery hose, liquid fuel is pumped into the UST, while a vapor recovery hose directs vapors displaced from the UST into the headspace of the tanker truck. Stage I vapor recovery is currently required for high-throughput gas stations in all states in the USA and in most countries.

2. Stage II vapor recovery technology can efficiently collect vapors expelled from vehicle tanks during refueling, thereby minimizing personal exposure of customers and workers to fuel vapors during dispensing of gas [63]. Recovered vapors are directed into the UST. Two technologies for stage II vapor recovery have been developed, the vaccum-assist method and the balance method. In the vacuum-assist method, contaminant-laden air is actively removed/pumped from the nozzle into the UST. In the balance method, displaced vapors are passively withdrawn by connecting the vapor recovery hose to the inlet of the vehicle tank via an airtight seal. The pressure increase in the headspace of the vehicle tank provides a driving force that seeks to push the vapors into the storage tank. Stage II vapor recovery has been required in many states of the USA and in other countries, although there is currently an effort to decommission stage II vapor recovery (see below).
3. Technology development at the hose and nozzle level can also contribute to reduced fuel releases. Low-permeation hoses, for instance, limit the release of gasoline vapors through the wall of the refueling hoses [64]. Dripless nozzles have been developed to minimize liquid spills that occur when the nozzle is moved between the fill pipe and the dispensing unit.
4. Passenger vehicles and trucks can be equipped with on-board refueling vapor recovery (ORVR) systems which direct vapors that, during vehicle refueling, would be released to the atmosphere into an activated carbon-filled canister in the vehicle [65, 66]. Collected vapors are later reintroduced into the vehicle's fuel system. However, canisters, motorcycles, and boats are not equipped with ORVR.
5. Impermeable liners underneath the concrete pads can reduce the risk of soil and groundwater contamination once environmental fuel releases, in liquid or vapor phase, have occurred. However, this technology might eventually result in air pollution, because liquid fuel that is hindered from moving downward in the concrete pad will tend to saturate the pavement and eventually evaporate into the atmosphere.
6. Finally, unburned fuel vapor can be released from an UST when the tank pressure exceeds the cracking pressure of the pressure/vacuum valve and it can be prevented by two pressure management techniques, burning or separation of air and fuel vapors. Released air/fuel vapors can be burned, however, which results in the release of combustion-related pollutants into the atmosphere. Alternatively, a semi-permeable membrane can be used to separate the air from the fuel vapors. Depressurization of the tank is then achieved by releasing the relatively clean air through the pressure/vacuum valve to the atmosphere.

When it comes to evaluating the efficiency of vapor recovery during liquid transfer between tanks, it is of upmost importance to consider potential releases from all tanks; they form a system. Otherwise, the overall efficiency of stage II vapor recovery cannot be understood. For instance, stage II vapor recovery based on the vacuum-assist method can negatively interfere with ORVR. In that case, no vapors are released from the vehicle tank and the stage II pump draws relatively clean air from the atmosphere into the storage tank. In the UST, this air will become saturated with fuel vapors that evaporate from the stored fuel. This results in pressurization of the UST and release of contaminant-laden air if the tank pressure exceeds the cracking pressure of the pressure/vacuum valve of the UST. This might occur immediately or at a later point in time. However, there are stage II systems that do not negatively interfere with ORVR including the balance method.

Estimates for the efficiency of pollution technologies are usually provided by the manufacturers. However, adoption of these technologies by gas station owners usually relies on the certification and quantification of efficiencies by independent parties. In the USA, the California Air Resources Board and EPA typically assume this role [36]. Consultants and environmental agencies have used these estimates to determine current releases of unburned fuel to the environment and to evaluate the effects of pollution prevention technology [67].

While many studies have found health benefits from pollution prevention technology intended to minimize chronic gasoline spills, these studies typically do not quantify overall financial benefits and costs. Instead, only equipment and maintenance cost are typically considered [68]. Adopting the new equipment can reduce fuel losses and reduce environmental cost and health risks. However, this new equipment comes with non-trivial upfront costs. It is therefore a concern that the related policy-making process of chronic fuel spills relies only on non-comprehensive cost estimates. Studies are needed that account for health care cost due to released pollutants and energy-saving benefits due to pollution prevention. Such econometric studies have, for example, been performed in the context of pollutant emissions from coal-fired power plant and commercial real estate development [69••, 70]. At times, there is also the perception that pollution prevention costs are only carried by the specific industry [71]. Adoption of the environmentally friendly technology could be slow when the firms have long equipment replacement cycles or when the firms do not have sufficient information to evaluate whether or not a switch to an environmentally friendly technology is in their private interests. It is, however, not clear that this apparent investment, in the form of prevention cost, might also be partly shouldered by customers and that this apparent cost might actually (at least in the long run) be beneficial to customers, gas station workers, nearby residents, and other populations that spend significant amounts of times in the proximity of gas stations (e.g., school children in nearby schools). Policy intervention is often expected to expedite the adoption of such environmental friendly technologies, in order to reduce the difference in the private and social values of adoption.

Efforts are currently underway that could potentially allow decommissioning stage II vapor recovery in the USA due to the widespread use of ORVR in the motor vehicle fleet [68]. However, the remaining legacy fleet without ORVR and all motorcycles and boats (lacking ORVR) can produce significant emissions during vehicle refueling, emissions that could be avoided by stage II vapor recovery. For the State of Maryland, it has been estimated that fuel consumption of non-ORVR-equipped vehicles was about 10 % in 2015 (Table 4 in [67]). These emissions can result in direct hydrocarbon exposures among vehicle owners during vehicle refueling as well as in passive exposure of other populations. A comprehensive cost analysis of the decommissioning of stage II recovery represents an opportunity to inform policy makers on their recommendation with regards to stage II recovery.

Conclusions

Even if only a small fraction of unburned fuel is lost during vehicle refueling and fuel storage, the cumulative release of fuel to the environment can be large if large total amounts of fuel are dispensed at gas stations. For instance, about 0.01 % of fuel can be spilled during the refueling process and up to about 0.5 % can be lost in vapor form if equilibrated gasoline vapors are released from a tank to the atmosphere during refueling (worst-case scenario). For a medium-size gas station, which sells 400,000 L of gasoline per month, this results in 480 L of spilled gasoline and in 24,000 L of liquid gasoline that is anually released in vapor form to the environment. Even though dilution can reduce concentrations of released contamination, research is needed to assess whether such releases represent an environmental health concern.

The potential for pollution prevention, moreover, is substantial. Technology has already been developed and partially employed that can efficiently decrease vapor losses and liquid spills. Particularly, when it comes to vapor losses, it is crucial to consider not only vapor recovery at the vehicle tank/nozzle but also at the storage tank, since vapors recovered at the nozzle are directed into the storage tank, from which they might be potentially released. While California has implemented the strictest regulations when it comes to preventing chronic hydrocarbon releases at gas stations, other highly industrialized states and nations do not employ the same standards for different reasons. For instance, pressure/vacuum valves on vent pipes of fuel storage tanks are not common in Canada, because they might freeze in the wintertime, potentially causing a tank implosion [6].

Relatively little research has been done on potential soil and groundwater contamination due to chronic releases of liquid fuel during vehicle refueling. Unlike catastrophic releases, such as LUST, chronic spills are not reported. Limited field investigations suggest that spilled fuel may penetrate concrete underneath dispensing pads to contaminate underlying sediment. However, it is possible that such soil contamination occurs routinely over the life span of a gas station and that this contamination pathway is masked or erroneously explained by leaks in the piping from the USTs to the dispensers. Overall, large-scale soil and groundwater contamination by fuel appears to be a lesser problem, because many of the toxic compounds in fuel are hydrophobic (including BTEX) and can therefore be expected not to travel too far in groundwater. However, customers, gas station workers, and nearby residents may get exposed to the hydrocarbons if groundwater is used as a drinking water supply or if fuel vapor intrusion in dwellings occurs.

Health effects of living near gas stations are not well understood. Adverse health impacts may be expected to be higher in metropolitan areas that are densely populated. Particularly affected are residents nearby gas stations who spend significant amounts of time at home as compared to those who leave their home for work because of the longer period of exposure. Similarly affected are individuals who spend time close to a gas station, e.g., in close by businesses or in the gas station itself. Of particular concern are children who, for example, live nearby, play nearby, or attend nearby schools, because children are more vulnerable to hydrocarbon exposure [72].

Potential future changes in fuel composition might pose new environmental health challenges as there is a history of adding even large amounts of toxic substances to fuel (Table 1). Changes in fuel composition could occur due to an increasing usage of biofuels, or to comply with air quality standards, which might also change over time. Chemicals newly added to fuel or changes in chemical concentrations can have unforeseen ramifications. One could argue that future fuel composition changes will be performed with more care; however, it was only in the 1990s, decades after the Safe Drinking Water Act (SDWA) was passed in 1974, that MTBE was added to gasoline without critically evaluating its transport behavior in groundwater and toxicity, a mistake which nowadays is considered avoidable [73]. Interestingly, ethanol, which has largely replaced MTBE, can inhibit biodegradation of BTEX, which is not the case for MTBE [74]. Given the complexities of chemical fate and transport in the environment and the potential for insufficient toxicity testing, using appropriate pollution prevention technology that minimizes release of unburned chemicals with known and unknown adverse health effects during fuel storage and transfer seems a wise, long-term, and cost effective idea given ever-changing fuel compositions.

Finally, employing efficient pollution prevention technology might be economically advantageous. The evaluation of economic benefits of pollution prevention technology needs to account not only for the cost of implementation and maintenance of such technology but also for public health burdens due to released pollutants and energy-saving benefits due to valuable hydrocarbons not wastefully released to the environment.

Acknowledgments This work was funded by a seed grant from the Environment, Energy, Sustainability and Health Institute at Johns Hopkins University.

Compliance with Ethics Guidelines

Conflict of Interest Markus Hilpert, Bernat Adria Mora, Jian Ni, Ana Rule, and Keeve Nachman declare that they have no conflict of interest.

Human and Animal Rights and Informed Consent This article does not contain any studies with human or animal subjects performed by any of the authors.

References

Papers of particular interest, published recently, have been highlighted as:
• Of importance
•• Of major importance

1. Wang Z et al. Characteristics of spilled oils, fuels, and petroleum products: 1. composition and properties of selected oils. United States Environmental Protection Agency. Report No.: EPA/600/R-03/072, 2003.
2. IARC, IARC monographs on the evaluation of carcinogenic risks to humans. Vol. 100F. 2012.
3. Karakitsios SP et al. Assessment and prediction of exposure to benzene of filling station employees. Atmospheric Environment. 2007;41(40):9555–69.
4. Javelaud B et al. Benzene exposure in car mechanics and road tanker drivers. International Archives of Occupational and Environmental Health. 1998;71(4):277–83.
5. U.S. Energy Information Administration. How much gasoline does the United States consume? 2015 [cited 2015 July 20]; Available from: http://www.eia.gov/tools/faqs/faq.cfm?id=23&t=10.
6. Statistics Canada. Gasoline evaporative losses from retail gasoline outlets across Canada 2009. Environment Accounts and Statistics Analytical and Technical Paper Series, 2012.
7. Dowd RM. Leaking underground-storage tanks. Environmental Science & Technology. 1984;18(10):A309–9.
8. Centers for Disease Control and Prevention. Facts about benzene. 2015 Available from: http://www.bt.cdc.gov/agent/benzene/basics/facts.asp.
9. Nadim F et al. United States experience with gasoline additives. Energy Policy. 2001;29(1):1–5.
10. Weaver JW , Exum LR , Prieto LM. Gasoline composition regulations affecting LUST sites. U.S. Environmental Protection Agency Office of Research and Development Washington, DC 20460, 2010. Report No.: EPA 600/R-10/001.
11. Needleman HL. The removal of lead from gasoline: historical and personal reflections. Environmental Research. 2000;84(1):20–35.
12. Grandjean P, Landrigan PJ. Developmental neurotoxicity of industrial chemicals. Lancet. 2006;368(9553):2167–78.
13. Thomas VM. The elimination of lead in gasoline. Annual Review of Energy and the Environment. 1995;20:301–24.
14. U.S. Environmental Protection Agency. National Ambient Air Quality Standards for ozone; final rule. Fed Reg. 2008;73:16436–514.
15. U.S. Environmental Protection Agency, Achieving clean air and clean water: The report of the blue ribbon panel on oxygenates in gasoline, 1999.
16. Squillace PJ et al. Review of the environmental behavior and fate of methyl tert-butyl ether. Environmental Toxicology and Chemistry. 1997;16(9):1836–44.
17. U.S. Energy Information Administration, Eliminating MTBE in gasoline in 2006. 2006.
18. U.S. Environmental Protection Agency, Fuel oxygenates (MTBE, TBA, and ethanol). 2015.
19. Morgester JJ, Fricker RL, Jordan GH. Comparison of spill frequencies and amounts at vapor recovery and conventional service stations in California. Journal of the Air & Waste Management Association. 1992;42(3):284–9.
20. Mueller EA. A survey and analysis of liquid gasoline released to the environment during vehicle refueling at service stations. Washington, DC: American Petroleum Institute; 1989.
21.• Hilpert M, Breysse PN. Infiltration and evaporation of small hydrocarbon spills at gas stations. Journal of Contaminant Hydrology. 2014;170:39–52. **This study examines for the first time the fate and transport of small fuel droplets spilled during vehicle refueling**.
22. Dakhel N et al. Small-volume releases of gasoline in the vadose zone: impact of the additives MTBE and ethanol on groundwater quality. Environmental Science & Technology. 2003;37(10):2127–33.
23. Charbeneau R.J., Groundwater hydraulics and pollutant transport 2006: Waveland Press, Inc.
24. Grady, S. and G. Casey, Occurrence and distribution of methyl tert-butyl ether and other volatile organic compounds in drinking water in the northeast and mid-Atlantic regions of the United States, 1993–98. Water Resources Investigations Report WRIR 00–4228. Geological Survey, U.S., 2001.
25. Leahy JG, Colwell RR. Microbial-degradation of hydrocarbons in the environment. Microbiological Reviews. 1990;54(3):305–15.
26. Stocking, A.S., et al., Evaluation of fate and transport of methyl tertiary butyl ether (MTBE) in gasoline following a small spill. In: Stanley, Anita, (eds.) Petroleum hydrocarbons and organic chemicals in ground water—prevention, detection, and remediation, Houston, Tex., Nov. 17–19, 1999. Proceedings.: National Ground Water Association, and American Petroleum Institute, 1999: p. 229–246.
27. Jacobs P. Permeabilität und Porengefüge Zementgebundener Werkstoffe. ETH Zürich: Switzerland; 1994.
28. Aria Environmental Inc., Underground Storage Tank Closure Report Chesapeake House – Exxon Facility (Northern Service

Station) I-95 Travel Plaza, North East, Cecil County, Maryland, 2014, Maryland Transportation Authority.
29. Latimer JS et al. Sources of petroleum-hydrocarbons in urban runoff. Water Air and Soil Pollution. 1990;52(1–2):1–21.
30. Ohe T, Watanabe T, Wakabayashi K. Mutagens in surface waters: a review. Mutation Research-Reviews in Mutation Research. 2004;567(2–3):109–49.
31. Hoffman EJ et al. Urban runoff as a source of polycyclic aromatic-hydrocarbons to coastal waters. Environmental Science & Technology. 1984;18(8):580–7.
32. Borden RC, Black DC, McBlief KV. MTBE and aromatic hydrocarbons in North Carolina stormwater runoff. Environmental Pollution. 2002;118(1):141–52.
33. Garcia MR et al. Assessment of polycyclic aromatic hydrocarbon influx and sediment contamination in an urbanized estuary. Environ Monit Assess. 2010;168(1–4):269–76.
34. Khan E, Virojnagud W, Ratpukdi T. Use of biomass sorbents for oil removal from gas station runoff. Chemosphere. 2004;57(7):681–9.
35. U.S. Environmental Protection Agency. Technical factsheet on: Benzene. 2015 Available from: http://www.epa.gov/ogwdw/pdfs/factsheets/voc/tech/benzene.pdf.
36. CARB. Vapor Recovery Program. 2015 Available from: http://www.arb.ca.gov/vapor/vapor.htm.
37. International Chemical Safety Cards (ICSC). ICSC #: 1400. 2015 Available from: http://www.cdc.gov/niosh/ipcsneng/neng1400.html.
38. van Wijngaarden E, Stewart PA. Critical literature review of determinants and levels of occupational benzene exposure for United States community-based case–control studies. Applied Occupational and Environmental Hygiene. 2003;18(9):678–93.
39. Hartle R. Exposure to methyl tert-butyl ether and benzene among service station attendants and operators. Environmental Health Perspectives. 1993;101 Suppl 6:23–6.
40. Periago JF, Zambudio A, Prado C. Evaluation of environmental levels of aromatic hydrocarbons in gasoline service stations by gas chromatography. Journal of Chromatography A. 1997;778(1–2):263–8.
41. Vainiotalo S et al. Customer exposure to MTBE, TAME, C6 alkyl methyl ethers, and benzene during gasoline refueling. Environmental Health Perspectives. 1999;107(2):133–40.
42. Egeghy PP, Tornero-Velez R, Rappaport SM. Environmental and biological monitoring of benzene during self-service automobile refueling. Environmental Health Perspectives. 2000;108(12):1195–202.
43. Akland GG. Exposure of the general population to gasoline. Environmental Health Perspectives. 1993;101 Suppl 6:27–32.
44. Jo W-K, Moon K-C. Housewives' exposure to volatile organic compounds relative to proximity to roadside service stations. Atmospheric Environment. 1999;33(18):2921–8.
45. Jo W-K, Oh J-W. Exposure to methyl tertiary butyl ether and benzene in close proximity to service stations. Journal of the Air & Waste Management Association. 2001;51(8):1122–8.
46. Terrés IMM et al. Assessing the impact of petrol stations on their immediate surroundings. Journal of Environmental Management. 2010;91(12):2754–62.
47. Watson JG, Chow JC, Fujita EM. Review of volatile organic compound source apportionment by chemical mass balance. Atmospheric Environment. 2001;35(9):1567–84.
48. Wallace LA. The exposure of the general population to benzene. Cell Biology and Toxicology. 1989;5(3):297–314.
49. Patel AS et al. Risk of cancer as a result of community exposure to gasoline vapors. Archives of Environmental Health. 2004;59(10):497–503.
50. U.S. Environmental Protection Agency. Benzene (CASRN 71-43-2). 2015 Available from: http://www.epa.gov/iris/subst/0276.htm.
51. National Institute for Occupational Safety and Health. NIOSH Pocket Guide to Chemical Hazards: Benzene. 2015 Available from: http://www.cdc.gov/niosh/npg/npgd0049.html.
52. Morton W, Marjanovic D. Leukemia incidence by occupation in the Portland-Vancouver metropolitan area. American Journal of Industrial Medicine. 1984;6(3):185–205.
53. Schwartz E. Proportionate mortality ratio analysis of automobile mechanics and gasoline service station workers in New Hampshire. American Journal of Industrial Medicine. 1987;12(1):91–9.
54. Lagorio, S., et al. Mortality of filling station attendants. Scand Journal Work Environ Health 1994: 331–338.
55. Lynge E et al. Risk of cancer and exposure to gasoline vapors. American Journal of Epidemiology. 1997;145(5):449–58.
56. Terry PD et al. Occupation, hobbies, and acute leukemia in adults. Leukemia Research. 2005;29(10):1117–30.
57. Hotz P, Lauwerys RR. Hematopoietic and lymphatic malignancies in vehicle mechanics. Critical Reviews in Toxicology. 1997;27(5):443–94.
58. Savitz, D.A.e.a., Contaminated water supplies at Camp Lejeune: assessing potential health effects 2009: National Academies Press.
59.•• Talbott EO et al. Risk of leukemia as a result of community exposure to gasoline vapors: a follow-up study. Environmental Research. 2011;111(4):597–602. **This study suggests a possible association between chronic low-level benzene exposure due to a leaking underground storage tank and increased risk of leukemia among residents that live nearby a gas station**.
60. Sanders PF, Hers I. Vapor intrusion in homes over gasoline-contaminated ground water in Stafford, New Jersey. Ground Water Monitoring and Remediation. 2006;26(1):63–72.
61. Caprino L, Togna GI. Potential health effects of gasoline and its constituents: a review of current literature (1990–1997) on toxicological data. Environmental Health Perspectives. 1998;106(3):115.
62. U.S. Environmental Protection Agency, Design criteria for Stage 1 vapor control systems—gasoline service stations. 1975.
63. U.S. Environmental Protection Agency, Technical guidance—stage II vapor recovery systems for control of vehicle refueling emissions at gasoline dispensing facilities, Volume I: Chapters, 1991.
64. McPhee, J., Gasoline dispensing facility (GDF) balance hose permeation study, 2008, California Air Resources Board (CARB)
65. U.S. Environmental Protection Agency. Commonly asked questions about ORVR. Available from: http://www.epa.gov/otaq/regs/ld-hwy/onboard/orvrq-a.txt.
66. Musser, G. and H. Shannon, Onboard control of refueling emissions. 1986: p. SAE Technical Paper 861560.
67. Meszler Engineering Services, Stage II emission reduction benefits. Report to the Maryland Department of the Environment. 2012.
68. Federal Register, Air quality: widespread use for onboard refueling vapor recovery and stage II waiver. Final Rule by US Environmental Protection Agency. Federal Register 2012. 77(95).
69.•• Currie J et al. Environmental health risks and housing values: evidence from 1,600 toxic plant openings and closings. American Economic Review. 2015;105(2):678–709. **This study provides an empirical framework for understanding the effects and the health cost of toxic atmospheric emissions. The research design could be applied to pollution prevention at gas stations. Such analysis could provide important policy recommendation in order to mitigate this type of environmental risk**.
70. Ni J. Environmental cost and economic benefit of commercial real estate development. Working Paper: Johns Hopkins University; 2015.

71. Fong M et al. California dry cleaning industry technical assessment report. State of California Air Resources Board: Technical report; 2006.
72. Irigaray P et al. Lifestyle-related factors and environmental agents causing cancer: an overview. Biomedicine & Pharmacotherapy. 2007;61(10):640–58.
73. McGarity TO. MTBE: a precautionary tale. Harvard Environmental Law Review. 2004;28(2):281–342.
74. Powers SE et al. The transport and fate of ethanol and BTEX in groundwater contaminated by gasohol. Critical Reviews in Environmental Science and Technology. 2001;31(1):79–123.
75. Jakobsson R et al. Acute myeloid-leukemia among petrol station attendants. Archives of Environmental Health. 1993;48(4):255–9.
76. U.S. Environmental Protection Agency, EPA requires phase-out of lead in all grades of gasoline. EPA press release – November 28, 1973. 1973.
77. U.S. Energy Information Administration (EIA), MTBE, oxygenates, and motor gasoline. 2000.
78. U.S. Environmental Protection Agency. Assessment of potential health risks of gasoline oxygenated with Methyl Tertiary Butyl Ether (MTBE). Washington, DC:Office of Research and Development, U.S. EPA. 1993. EPA/600/R-93/206.

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Attachment "F"

2019 Study
Vent pipe emissions from storage tanks at gas stations: Implications for setback distances

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Attachment "F"

Science of the Total Environment 650 (2019) 2239–2250

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Vent pipe emissions from storage tanks at gas stations: Implications for setback distances

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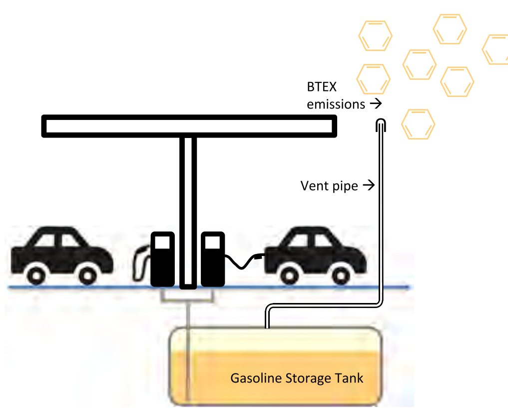
HIGHLIGHTS

- At gas stations, fuel vapors are released from storage tanks through vent pipes.
- We measured vent pipe flow rates and tank pressure at high temporal resolution.
- Vent emission factors were >10 times higher than previous estimates.
- Modeling was used to examine exceedance of benzene short-term exposure limits.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 3 July 2018
Received in revised form 11 September 2018
Accepted 23 September 2018
Available online 24 September 2018

Editor: Pavlos Kassomenos

Keywords:
Gas stations
Benzene emissions
Setback distances
Air pollution modeling
Measurements

ABSTRACT

At gas stations, fuel vapors are released into the atmosphere from storage tanks through vent pipes. Little is known about when releases occur, their magnitude, and their potential health consequences. Our goals were to quantify vent pipe releases and examine exceedance of short-term exposure limits to benzene around gas stations. At two US gas stations, we measured volumetric vent pipe flow rates and pressure in the storage tank headspace at high temporal resolution for approximately three weeks. Based on the measured vent emission and meteorological data, we performed air dispersion modeling to obtain hourly atmospheric benzene levels. For the two gas stations, average vent emission factors were 0.17 and 0.21 kg of gasoline per 1000 L dispensed. Modeling suggests that at one gas station, a 1-hour Reference Exposure Level (REL) for benzene for the general population (8 ppb) was exceeded only closer than 50 m from the station's center. At the other gas station, the REL was exceeded on two different days and up to 160 m from the center, likely due to non-compliant bulk fuel deliveries. A minimum risk level for intermediate duration (>14–364 days) benzene exposure (6 ppb) was exceeded at the elevation of the vent pipe opening up to 7 and 8 m from the two gas stations. Recorded vent emission factors were >10 times higher than estimates used to derive setback distances for gas stations. Setback distances should be revisited to address temporal variability and pollution controls in vent emissions.

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https://doi.org/10.1016/j.scitotenv.2018.09.303

Attachment "F"

1. Introduction

In the US, approximately 143 billion gal (541 billion L) of gasoline were dispensed in 2016 at gas stations (EIA, 2017) resulting in release of unburned fuel to the environment in the form of vapor or liquid (Hilpert et al., 2015). This is a public health concern, as unburned fuel chemicals such as benzene, toluene, ethyl-benzene, and xylenes (BTEX) are harmful to humans (ATSDR, 2004). Benzene is of special concern because it is causally associated with different types of cancer (IARC, 2012). Truck drivers delivering gasoline and workers dispensing fuel have among the highest exposures to fuel releases (IARC, 2012). However, people living near or working in retail at gas stations, and children in schools and on playgrounds can also be exposed, with distance to the gas stations significantly affecting exposure levels (Terres et al., 2010; Jo & Oh, 2001; Jo & Moon, 1999; Hajizadeh et al., 2018). A meta-analysis (Infante, 2017) of three case-control studies (Steffen et al., 2004; Brosselin et al., 2009; Harrison et al., 1999) suggests that childhood leukemia is associated with residential proximity to gas stations.

Sources of unburned fuel releases at gas stations include leaks from storage tanks, accidental spills from the nozzles of gas dispensers (Hilpert & Breysse, 2014; Adria-Mora & Hilpert, 2017; Morgester et al., 1992), fugitive vapor emissions through leaky pipes and fittings, vehicle tank vapor releases when refueling, and leaky hoses, all of which can contribute to subsurface and air pollution (Hilpert et al., 2015). Routine fuel releases also occur through vent pipes of fuel storage tanks but are less noticeable because the pipes are typically tall, e.g., 4 m. These vent pipes are put in place to equilibrate pressures in the tanks and can be located as close as a few meters from residential buildings in dense urban settings (Fig. 1).

Unburned fuel can be released from storage tanks into the environment through "working" and "breathing" losses (Yerushalmi & Rastan, 2014). A working loss occurs when liquid is pumped into or out of a tank. For a storage tank, this can happen when it is refilled from a tanker truck or when fuel is dispensed to refuel vehicles (Statistics Canada, 2009) if the pressure in the storage tank exceeds the relief pressure of the pressure/vacuum (P/V) valve (EPA, 2008). P/V valve threshold pressures are typically set to around +3 and −8 in. of water column (iwc) (7.5 and −20 hPa). However, P/V valves are not always used, particularly in cold climates, as valves may fail under cold weather conditions (Statistics Canada, 2009).

Breathing losses occur when no liquid is pumped into or out of a tank because of vapor expansion and contraction due to temperature and barometric pressure changes or because pressure in the storage

Fig. 1. The three vent pipes (enclosed by the red ellipse) on the right side of the convenience store of a gas station are <10 m away from the residential building. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

tank may increase when fuel in the tank evaporates (Yerushalmi & Rastan, 2014; EPA, 2008). Although delayed or redirected by the P/V valve, breathing emissions can be significant and represent an environmental and health concern (Yerushalmi & Rastan, 2014).

Stage I vapor recovery systems, put in place to prevent working losses while delivering fuel to a station, collect the vapors displaced while loading a storage tank, redirecting them into the delivery truck. Stage II vapor recovery systems minimize working losses while delivering gas from the storage tank to the customer's car. During Stage II vapor recovery, gasoline vapors can be released through the vent pipe, if the sum of the flow rates of the returned volume and of the fuel evaporating within the storage tank is greater than the volume of liquid gasoline dispensed (Statistics Canada, 2009). We refer to this scenario as pressure while dispensing (PWD). In theory, a properly designed Stage II vapor recovery system should not have working losses, although in practice this is not typically the case (McEntire, 2000).

Regulations on setback distances for gas stations are based on lifetime cancer risk estimates. Several studies have assessed benzene cancer risk near gas stations (Atabi & Mirzahosseini, 2013; Correa et al., 2012; Cruz et al., 2007; Edokpolo et al., 2015; Edokpolo et al., 2014; Karakitsios et al., 2007). Based on cancer risk estimations, the California Air Resources Board (CARB) recommended that schools, day cares, and other sensitive land uses should not be located within 300 ft. (91 m) of a large gas station (defined as a facility with an annual sales volume of 3.6 million gal = 13.6 million L or greater) (CalEPA/CARB, 2005). This CARB recommendation has not been adopted by all US states, and within states setback distances can depend on local government. Notably, CARB regulations do not account for short term exposure limits and health effects. An important limitation of existing regulations is the use of average gasoline emission rates estimated in the 90s that do not consider excursions (CAPCOA, 1997).

The main objective of this study is to evaluate fuel vapor releases through vent pipes of storage tanks at gas stations based on vent emission measurements conducted at two gas stations in the US in 2009 and 2015, including the characterization of excursions at a high temporal resolution (~minutes) and meteorological conditions at an hourly temporal resolution. In addition, we performed hourly simulations of atmospheric transport of emitted fuel vapors to inform regulations on setback distances between gas stations and adjacent sensitive land uses by comparing modeled benzene concentrations to four 60-min benzene exposure limits: an acute Reference Exposure Level (REL) for infrequent (once per month or less) exposure (WHO, 2010) and Emergency Response Planning Guidelines ERPG-1, ERPG-2 and ERPG-3 (AIHA, 2016). Finally we compared simulated benzene levels to a Minimal Risk Level (MRL) for benzene for intermediate exposure duration (14 to 364 days) (ATSDR, 2018) because that duration window includes our duration of data collection. See Table 1 for the various benzene exposure limits and issuing agencies.

2. Methods

Although we provide SI unit conversions, we report some measures in English engineering units (ft, gal, and lb) as regulatory agencies such as CARB use these units.

2.1. Sites

Data for this study were obtained from vent release measurements conducted at two gas stations as part of technical assistance to the gas stations to quantify fuel vapor losses through the vent pipes of their storage tanks. A motivation for conducting the measurements was to perform a cost-benefit analysis to compare the economic losses due to the lost fuel versus the cost of technologies that reduce the emissions. The exact location of the two gas stations is not revealed for confidentiality reasons. The gas station managers and staff who authorized the

Table 1
Benzene exposure limits, to which we compared simulation results. For unit conversion, we assumed a temperature of 25 °C, i.e., 1 ppm = 3194 μg/m³ (CAPCOA, 1997).

Agency	Name	Value (ppb)	Value (μg/m³)	Exposure duration
California Office of Environmental Health Hazard Assessment (OEHHA)	REL	8	26	1 h
American Industrial Hygiene Association (AIHA)	ERPG-1	50	159,700	1 h
AIHA	ERPG-2	150	479,100	1 h
AIHA	ERPG-3	1000	3,194,000	1 h
Agency for Toxic Substances and Disease Registry (ATSDR)	MRL	6	19	14 to 364 days

ERPG = Emergency Response Planning Guidelines. The primary focus of ERPGs is to provide guidelines for short-term exposures to airborne concentrations of acutely toxic, high-priority chemicals.

collection and analysis of these data have not been involved in the current manuscript.

The first gas station, "GS-MW," was located in the US Midwest and is a 24-hour operation. The study was conducted from December 2014 to January 2015 for 20 full days, and fuel sales $\dot{V}_{sales}$ were about 450,000 gal (1.7 million L) per month. Fuel deliveries to the gas station usually took place during the nighttime. The second gas station, "GS-NW," was located on the US Northwest coast and closed at night. Hours of operation were between 6:00 am and 9:30 pm on weekdays and between 7 am and 7 pm on weekends. That study was conducted in October 2009 for 18 full days, and fuel sales were $\dot{V}_{sales}$ ~700,000 gal (2.6 million L) per month.

Both gas stations are considered to be high-volume, because they dispense >3.6 million gal of gasoline (both regular and premium) per year (CalEPA/CARB, 2005), and fuel was stored in underground storage tanks (USTs), which is typical in the US. Both gas stations had Stage II vapor recovery installed using the vacuum-assist method. In that method, gasoline vapors, which would be ejected into the atmosphere as a working loss during refueling of customer vehicle tanks, are collected at the vehicle/nozzle interface by a vacuum pump. The recovered vapors are then directed via a coaxial hose back into the combined storage tank ullage (head space) of the gas station. Stage I vapor recovery was also used at both gas stations during fuel deliveries. Both sites had a 3-inch diameter (7.5 cm) single above-grade vent pipe with below-grade manifold that connected the vent lines from several USTs; the cracking pressures of the P/V valves were set to +3 and −8 iwc (+7.5 and −20 hPa).

2.2. Vent emission measurements

To quantify evaporative fuel releases through the vent pipe of a storage tank, the volumetric flow of the mixture of gasoline vapor and air was measured in the vent pipe. A dry gas diaphragm flow meter (American Meter Company, Model AC-250) was used. For each cubic foot (28 L) of gas flowing through the meter, a digital pulse was generated. Every minute, the number of pulses was read out and stored together with date and time on a data logger. Gas flow meters were obtained from a distributor calibrated and equipped with temperature compensation and a pulse meter.

To determine the time-dependent volumetric flow rate $Q(t)$ of the gasoline vapor/air mixture through the vent pipe, the time series of measured flow volumes were integrated over an averaging period (15 or 60 min) and divided by the duration of that period. I.e., $Q(t)$ is given by the number of pulses registered by the gas flow meter in a time window multiplied by 1 cubic foot and divided by the averaging time. The 15-minute averaging time was chosen to visualize time-dependent data, while the 60-minute averaging time was chosen because air pollution simulations were performed at that resolution.

Gas pressure p in the ullage of the storage tank was measured to assess vent emission patterns. For instance, releases can occur when the pressure exceeds the cracking pressure of the P/V valve in the vent pipe (the dry gas flow meter was fitted with a P/V valve on the outlet). Pressure was measured with a differential pressure sensor (Cerabar PMC 41, Endress + Hauser) every 4 s, and 2-minute average values were stored. The sensor range was scaled from −15 to +15 iwc (−37 to +37 hPa), with a full scale accuracy of 0.20%. We also obtained 15- and 60-minute averaged tank pressure data $p(t)$ where averages represent the means of the 2-minute average pressure measurements taken during each time window.

2.3. Descriptive analysis

For the 60-minute flow rate, we calculated medians and inter quartile ranges (IQRs). To illustrate diurnal fluctuations in vapor emissions, we created box plots for the 60-minute flow rate distribution that occurred during each hour of the day. Spearman correlation coefficients between the time series for pressure and flow rate were calculated to evaluate whether pressure can be used to infer vent emissions.

To estimate the mass flow rate of gasoline $\dot{m}_{gas}$ that is released through the vent pipe in the form of a mixture of gasoline vapors and fresh air, we assumed, following the protocol of a study by the California Air Pollution Control Officers Association (CAPCOA) that assessed risks from fuel emissions from gas station (Appendix D-2 (CAPCOA, 1997)), that the density of gasoline vapors in this mixture is given by $\rho_{gas}^{(v)} = 0.3 \times 65$ lb / 379 ft³ $= 0.824$ kg/m³, i.e., the molar percentages of gasoline and air were 30% and 70%, respectively. Then the volumetric flow rate Q can be converted into a mass flow rate of the vaporized gasoline:

$$\dot{m}_{gas} = \rho_{gas}^{(v)}\ Q \quad (1)$$

To arrive at vent emission factors, we first calculated the mean volumetric flow rate $\overline{Q}$, and then the mean mass flow rate $\overline{\dot{m}}_{gas} = \rho_{gas}^{(v)}\ \overline{Q}$. From the latter, one can calculate the vent emission factor

$$EF_{vent} = \overline{\dot{m}}_{gas}/\dot{V}_{sales} \quad (2)$$

For EF_{vent}, CARB uses units of pounds of emitted gasoline vapors (also called total organic gases (TOG)) per 1000 gal dispensed, or more briefly lb/kgal where kgal stands for kilogallons.

As we were not able to measure benzene levels in the tank ullage, we assumed like the CAPCOA study (Section C) that the density of the mixture of gasoline vapors and fresh air was $\rho_{mix}^{(v)} = 1.05$ lb/ft³ $=$ 1.682 kg/m³ and that the emitted gasoline vapor/air mixture contained 0.3% of benzene by weight (CAPCOA, 1997). Therefore, the mass flow rate of benzene through the vent pipe was estimated as follows:

$$\dot{m}_{benz} = 0.003\ \rho_{mix}^{(v)}\ Q \quad (3)$$

2.4. Air pollution modeling

We used the AERMOD Modeling System developed by the US Environmental Protection Agency (EPA) to model the dispersion of benzene vapors released into the environment through vent pipes of fuel storage tanks and from other sources (Cimorelli et al., 2005). AERMOD simulates atmospheric pollutant transport at a 1-hour temporal resolution. 3D polar grids were created with the gas station in the origin and potential receptors at different radial distances (up to 170 m) and angles (10°

increments). The grids were placed at the ground level ($z = 0$ m), in the breathing zone ($z = 2$ m), and at the 2nd floor level ($z = 4$ m) where the vent pipe emissions were assumed to occur. The topography was simplified for modeling purposes consistent with the CAPCOA study (CAPCOA, 1997), i.e., the terrain was assumed to be flat with no buildings present. Vent pipe emissions were modeled as a capped point source. Chemical reactions of benzene were not modeled, as residence times of atmospheric benzene are on the order of hours or even days (ATSDR, 2007), i.e. much longer than the travel time of benzene vapors across the 340-m diameter model domain.

For the period of time when vent emission measurements were made, we obtained meteorological data at a 1-hour temporal resolution that are representative for the geographic locations of the two gas stations. Table SI-1 provides descriptive statistics of that data. The time series were used in AERMOD to model the transport of benzene in the temporally varying turbulent atmosphere. We also used the 1-hour average time series of benzene emission rates (Eq. (3)) as an input into AERMOD.

To evaluate at each grid point whether OEHHA's acute REL or AIHA's ERPG levels were exceeded at least once, we determined maximum 1-hour average benzene concentrations that were simulated for about three weeks. To evaluate how often the OEHHA REL was exceeded at each grid point in the breathing zone, we created plots indicating the number of exceedances and the day when the maximum benzene level was observed.

To facilitate comparison to published benzene measurements around gas stations, we determined for each simulated radial distance from a gas station the mean of the average concentrations simulated for each ten degree increment on the radius around the gas station.

3. Results: vent releases

3.1. Times series of tank pressure and flow rate

Fig. 2 shows the time-series data for the volumetric flow rate Q of the gasoline vapor/air mixture through the vent pipe and tank pressure p that we collected at the two gas stations. At GS-MW, little vapor was typically released in the late night and in the very early morning, while releases were generally much higher during the daytime and evenings, presumably when more fuel was dispensed (Fig. 2a). Occasionally, no vapor releases occurred for several hours. While we do not have access to time of fuel delivery records, field visits indicate that time periods with no releases coincide with fuel deliveries. For instance, fuel delivery likely occurred on January 6 at 7 pm (see Fig. 3a; an amplification of data shown in Fig. 2a). As a result, the UST pressure dropped by about 10 hPa, far below the cracking pressure of the P/V valve. The decreased gas pressure in the ullage increased until the cracking pressure of the P/V valve was reached. A very small vapor release (~2 L/min) was observed briefly on the next day at 2 am. The vapor flow rate becomes relatively large again, ~12 L/min, only after 6 am, i.e., 11 h after fuel delivery.

Fig. 3b amplifies a major vapor release at GS-MW. The UST pressure significantly exceeded the cracking pressure of the P/V valve and rose rapidly up to 37 hPa, which coincides with vapors being released at a high flow rate (15-min average) of about 470 L/min.

At GS-NW, vapor releases followed a quite different pattern (Fig. 2b). Contrary to GS-MW, vapor releases occurred in a cyclical pattern, and tended to be higher in the late night and in the very early morning when the gas station was closed.

3.2. Statistics of vapor emissions

The average volumetric flow rate $\overline{Q}$ through the vent pipe for the entire period of time during which measurements were taken was $\overline{Q} =$ 7.9 L/min for GS-MW and $\overline{Q} =$ 15.4 L/min for GS-NW, which is consistent with the higher sales volume $\dot{V}_{sales}$ of GS-NW. These emissions consist of a mixture of gasoline vapors and air. Using Eq. (1), the volumetric flow rates were converted into average mass flow rates of gasoline: $\overline{\dot{m}}_{gas} = 0.39$ kg/h for GS-MW and $\overline{\dot{m}}_{gas} = 0.76$ kg/h for GS-NW. Using Eq. (2), we determined a vent emission factor $EF_{vent}=$ 0.17 kg per 1000 L = 1.4 lb/kgal for GS-MW and $EF_{vent}=$ 0.21 kg per 1000 L = 1.7 lb/kgal for GS-NW.

The medians (IQRs) for the 60-minute averaged flow rate Q (L/min) were 6.1 (1.9, 10.9) for GS-MW and 16.0 (12.7, 18.4) for GS-NW. For GS-MW, the mean is larger than the median, indicating a more skewed distribution of flow rates when compared to GS-NW. Also the first quartile is much lower than the median for GS-MW, indicating that there are periods of time during which little emissions occurred. Conversely, GS-NW was releasing emissions more consistently.

Fig. 4a shows boxplots illustrating the distribution of flow rate Q for each hour of the day at GS-MW. Less vapor was released between 10 pm and 4 am, even though the gas station was in operation, albeit at lower activity levels. The flow rate Q at GS-NW (Fig. 4b) had fewer outliers, and the highest outlier was an order of magnitude lower than the highest one at GS-MW. Emissions were highest between 1 and 3 am, when the gas station was closed.

The Spearman correlation coefficients between tank pressure p and vent flow rate Q were $r = 0.58$ for GS-MW and $r = 0.85$ for GS-NW. Thus, vent releases are moderately and strongly correlated with tank pressure, respectively. Table 2 summarizes statistical properties of vent emissions at the two gas stations.

4. Results: air pollution modeling

4.1. Emission sources and rates

Vent pipe emissions of benzene were modeled at a 1-hour temporal resolution as described in Section 2.4. However, they are not the sole source of gasoline emissions at gas stations. Accidental spills from nozzles regularly occur near the dispensers, "refueling losses" can occur when gasoline vapors are released from the vehicle tank during refueling due to the rising liquid levels in the tanks, fuel vapors are released from permeable dispensing hoses, and "fugitive" or leakage emissions occur with driving force derived from storage tank pressure. In Section A of Supporting material, we detail how these other emission sources were modeled. Table 3 summarizes estimated mean emission rates. Note that the vent pipe losses are much greater than other losses.

4.2. Predicted benzene levels

Fig. 5 shows for both gas stations and at each grid point the maximum 1-hour average benzene concentration observed during the simulated periods in time. Benzene levels depend significantly on elevation within a 50-meter radius around the centers of the gas stations. Close to the centers of the gas stations, benzene levels are higher at the 4-m elevation and at ground level due to vent pipe emissions, which represent the largest emission source (Table 3). Further than 50 m away from the center, the vertical concentration differences become less obvious due to dispersion causing vertical mixing of benzene vapors.

At GS-MW, the 1-hour acute REL of 26 $\mu g/m^3$ was exceeded 160 m away from the center of the gas station, at the location ($x = 158$ m, $y = 28$ m) both at ground level and in the breathing zone. At grid points with a distance >50 m from the center of the gas station, the REL was exceeded at most once (Fig. SI-1a). However, the exceedance at different grid points did not occur on the same day (Fig. SI-1b). Within the 20 days during the measurement campaign, exceedances occurred on the 4th and 13th of January.

At GS-NW, the furthest REL exceedance occurred at 50 m from the center of the gas station at the grid point ($x = -38$ m, $y = 32$ m) as

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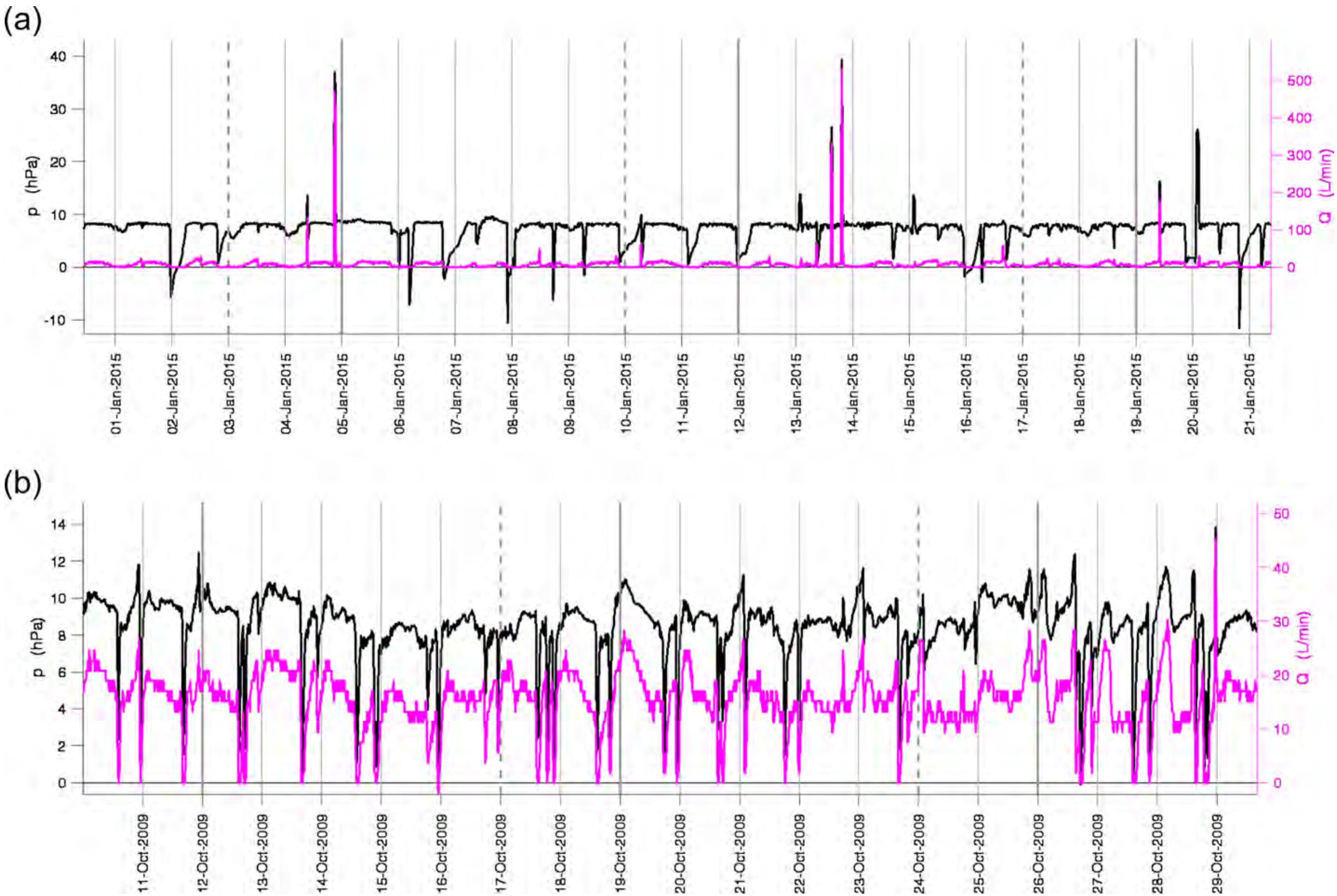

Fig. 2. Time series of ullage pressure *p* (left ordinate) and volumetric flow rate *Q* (right ordinate) for (a) GS-MW and (b) GS-NW. Horizontal tick marks indicate midnights. The vertical dashed and thick solid gray lines enclose weekends.

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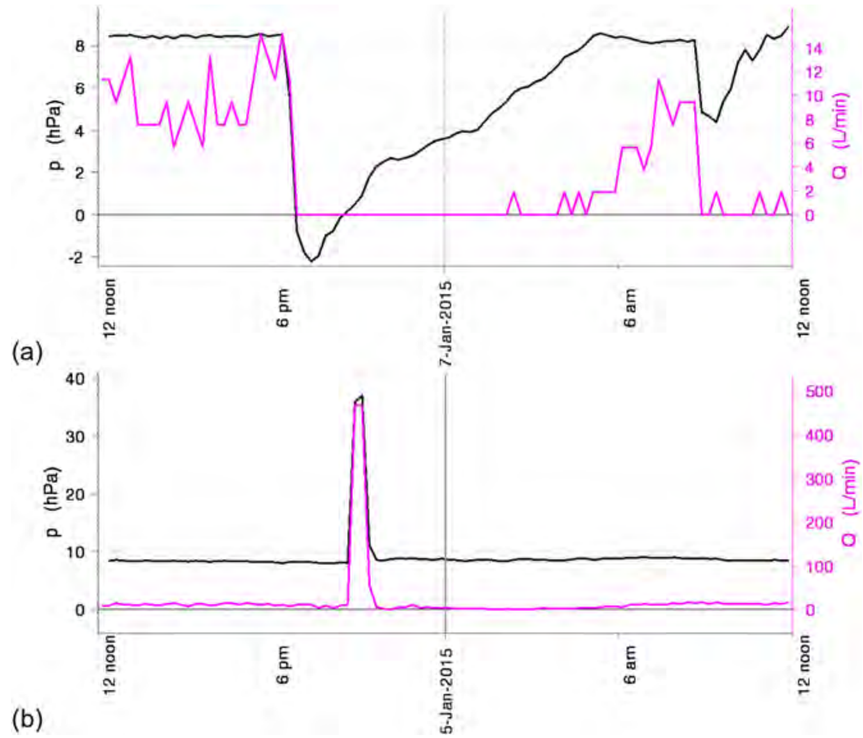

Fig. 3. Amplifications of time series data (15-minute averages) for GS-MW. (a) Tank pressure *p* became negative after fuel delivery. As a result, vent emission ceased for several hours. (b) A major vapor release (burst) likely occurred when the cracking pressure of the P/V valve was significantly exceeded at around 9 pm during a non-compliant bulk fuel delivery.

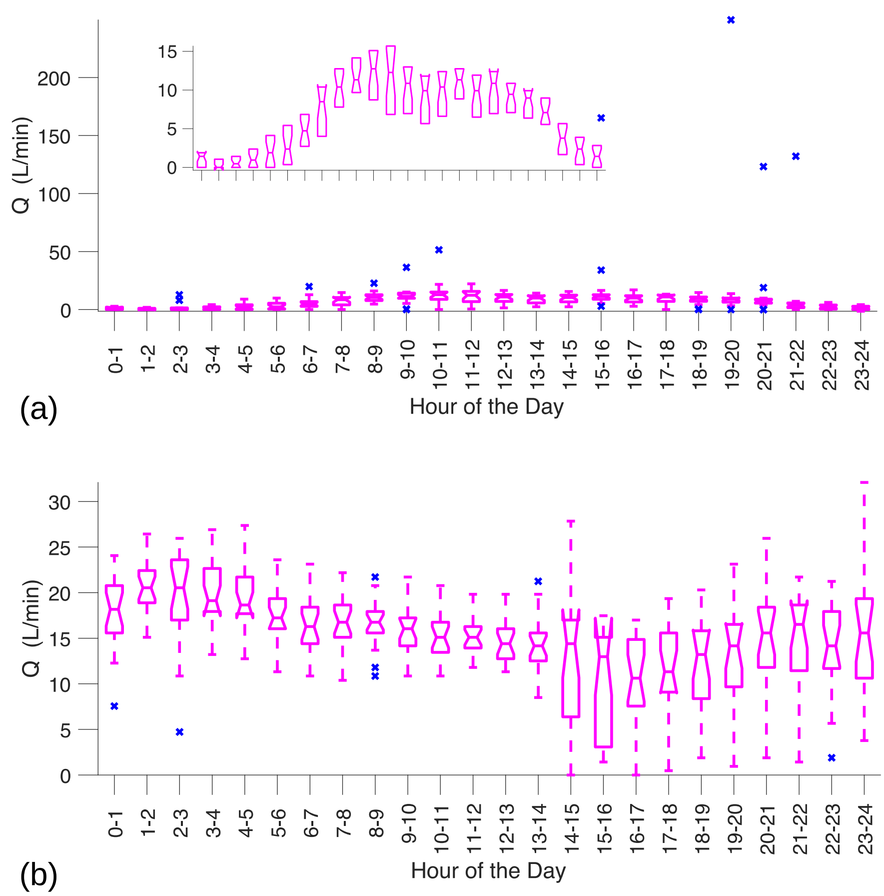

Fig. 4. Distribution of vent emissions *Q* observed for each hour of the day at (a) GS-MW [insert shows the IQRs of *Q*] and (b) GS-NW gas stations. In (a), outliers make it difficult to recognize variations in median hourly emissions. We therefore plotted in the inset only the IQRs. Boxes indicate median and IQR, whiskers values within 1.5 the IQR, and asterisks outliers.

Table 2
Summary of gas station characteristics and vent emissions.

	GS-MW	GS-NW	Units
Sales volume $\dot{V}_{sales}$	450,000	700,000	gal/month
Volumetric flow rates (of gasoline vapor/air mixture)			
Mean $\overline{Q}$	7.9	15.4	L/min
Median (IQR) of 60-min average	6.1 (1.9, 10.9)	16.0 (12.7, 18.4)	L/min
Maximum of 60-min average	250	32.1	L/min
Vent emission factor EF_{vent}	1.4	1.7	lb/kgal
Mass flow rates of gasoline (w/o air)			
Mean $\overline{\dot{m}}_{gas}$	0.39	0.76	kg/h
Maximum of 60-min average	12.3	1.6	kg/h
Correlation coefficient			
Between Q and p	0.58	0.85	–

shown in Fig. SI-2a. At a distance of 40 m, the REL was exceeded three times at one grid point (260° angle), and at 35 m four times at two grid points (250° and 260° angles) (Fig. SI-2b). At a distance of 20 m, the REL was exceeded at 30 (out of 36) grid points, and on nine different days.

Average benzene levels are shown in Fig. 6 for both gas stations. The MRL is exceeded at the elevation of the vent pipe opening, $z = 4$ m, up to 7 m away from for GS-MW and up to 8 m from GS-NW. Fig. 7 shows the average benzene concentration as a function of distance at an elevation of 2 m. Close to the center, benzene levels first increase and then decrease.

5. Discussion

5.1. Vent emission factors

We present unique data on vent emissions from USTs at two gas stations. Emissions can be compared to vent losses assumed by CAPCOA (CAPCOA, 1997). For a gas station with Stage I and II vapor recovery technology and a P/V valve on the vent pipe of the UST (Scenario 6B), the CAPCOA study assumed loading losses of 0.084 and breathing losses of 0.025 lb/kgal dispensed. The total loss of gasoline through the vent pipe is the sum of the two and amounts to a vent emission factor $EF_{vent}=$ 0.109 lb/kgal. Based on actual measurements in two fully functioning US gas stations, we obtained EF_{vent} values of 1.4 lb/kgal for GS-MW and 1.7 lb/kgal for GS-NW, more than one order of magnitude higher than the CAPCOA estimate. While the difference between our measurements and the CAPCOA estimates may appear surprising, it is important to consider that the CAPCOA estimates are based on relatively few measurements and some unsupported assumptions (Aerovironment, 1994), particularly with regard to uncontrolled emissions due to equipment failures or defects (Appendix A-5 (CAPCOA, 1997)).

5.2. Pressure measurements

Tank ullage pressure p was moderately to strongly positively correlated with vent flow rate Q, likely because exceedance of the cracking pressure of the P/V valve causes a vent release. Thus pressure measurements can be used to infer vent releases. Real-time detection of equipment failures and leaks via so-called in-station diagnostics systems is based on our observed correlations between p and Q.

Table 3
Mean benzene emission rates $\dot{m}_{benz}$ for the two gas stations.

Emission source	Benzene emissions (mg/s)	
Gas station	GS-MW	GS-NW
Vent pipe	0.80	1.55
Spillage	0.39	0.65
Refueling	0.41	0.69
Hose permeation	0.06	0.10
Total	1.67	2.90

5.3. Diurnal fluctuations in vent emissions

Diurnal vent emissions were quite different at the two gas stations. At GS-MW, a 24-hour operation, vent emissions were high during the daytime, presumably due to PWD. Emissions ceased at night, likely because less gasoline was dispensed and fuel deliveries with relatively cool product were frequent. Evaporative losses could also have been lower at night because the cooler delivered fuel would cause slight contraction of the liquid phase with corresponding growth in the ullage volume while at the same time lowering the vapor pressure of gasoline in the UST.

At GS-NW, vent pipe releases occurred most of the time, during the daytime when fuel was dispensed (PWD) and at night when the gas station was closed. Vent releases were higher when the gas station was closed, suggesting that during the day-time Stage II vapor recovery resulted in the injection of vapors into the storage tank that were not completely equilibrated with the liquid gasoline. During night-time, the gradual equilibration of unsaturated air in the ullage of the UST with gasoline vapors could then have caused exceedance of the cracking pressure of the P/V valve and consequently vapor release. It seems counterintuitive that less nighttime emissions occurred at the gas station where fuel was dispensed. However, while fuel is being dispensed, the outgoing liquid creates additional ullage volume, and depending on excess air ingestion rate, a negative pressure could result that lowers vent pipe emissions.

Dispensing fuel to customer vehicles and the associated Stage II vapor recovery system interact with vent emissions and can even cause vent emission during PWD, because the vacuum-assist method can negatively interfere with Onboard Refueling Vapor Recovery (ORVR) installed in customer vehicles (EPA, 2004). However, Stage II vapor recovery is not obsolete. It can be used in conjunction with ORVR to minimize exposure of gas station customers and workers to benzene due to working losses (Cruz-Nunez et al., 2003), particularly when customer vehicles are not equipped with ORVR (e.g., older vehicles, boats, motorcycles) or small volume gasoline containers are refueled. Enhanced Stage II vapor recovery technology can significantly reduce vapor emissions both at the nozzle and from UST vent pipes (CARB, 2013).

5.4. Fuel deliveries and accidental vent releases

Based on observations and interpretation of time series of the tank pressure data, it is likely that the peak vent emissions (e.g., Fig. 3b) were partly due to non-compliant bulk fuel drops where the Stage I vapor recovery system either was not correctly hooked up by the delivery driver or to hardware problems with piping and/or valves. This

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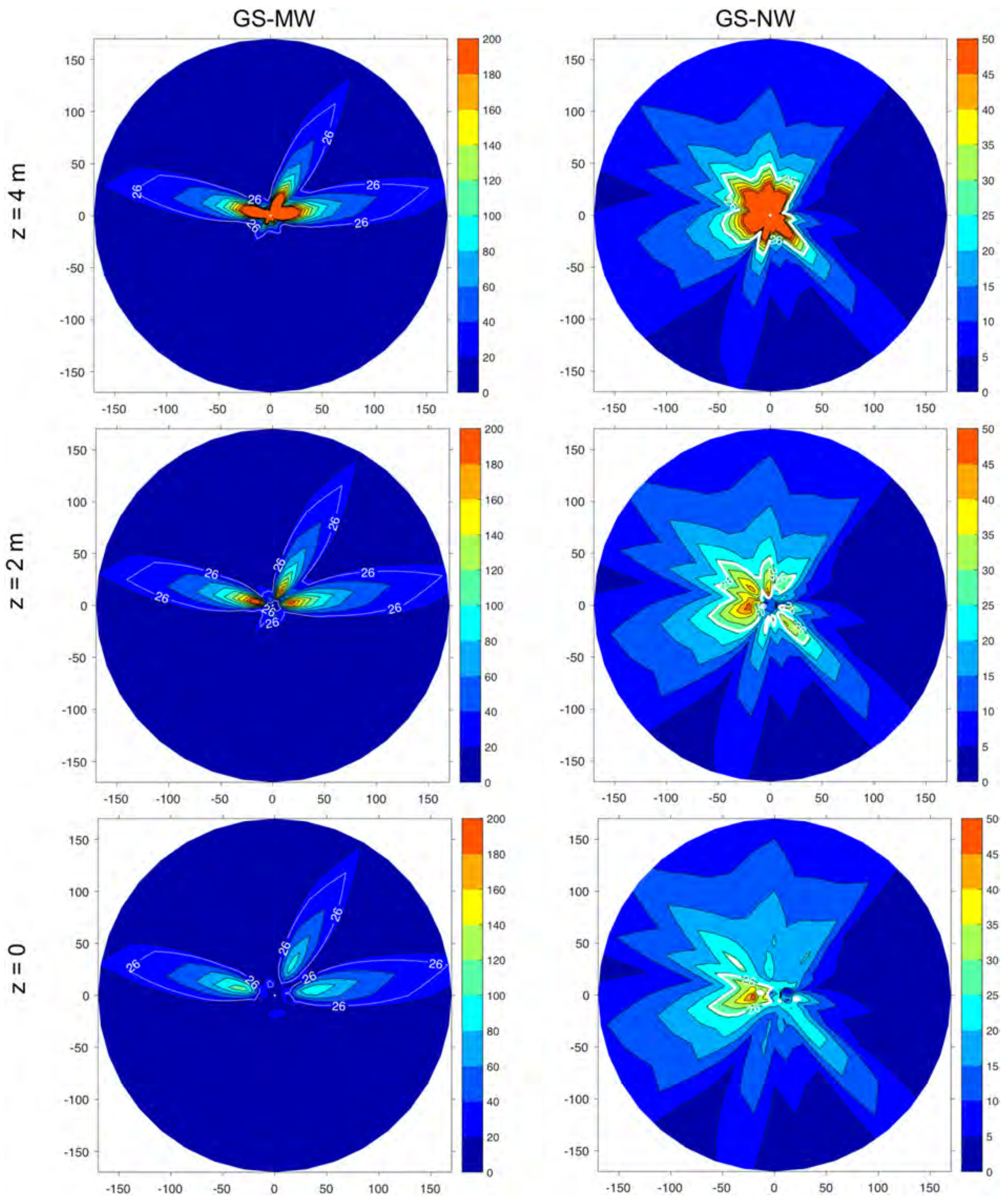

Fig. 5. Modeled maximum benzene concentrations for GS-MW and GS-NW at three different elevations *z*. The *x*- and *y*-axes indicate horizontal coordinates in meters. The color indicates benzene levels in units of μg/m^3. Left column: time series of benzene emission rates were used. Right column: average benzene emission rate was used in the modeling. The white isoline indicates OEHHA's acute REL of 26 μg/m^3 = 8 ppb.

conjecture is consistent with typical US storage tank volumes (~10,000 to 30,000 gal). Assuming that Phase I vapor recovery did not work at all and that 10,000 gal (~38,000 L) of fuel were delivered, the working loss (volume of gasoline vapor/air mixture released to the atmosphere through the vent pipe) is 38,000 L. It is also reasonable to assume that delivery lasted less than 1 h. According to Table 2, the maximum hourly flow rate through the vent pipe was 250 L/min at GS-MW, which would result in a maximum cumulative vapor release of 15,000 L within this hour. The measured maximum cumulative release underestimates the assumed working loss of 38,000 L. This could be due to a fuel delivery, which involved dropping fuel from multiple compartments of a tanker truck, with the vapor return hose not being correctly hooked up for only some of the emptied compartments.

At GS-MW, UST pressure decreased after fuel delivery (causing vent emissions to cease for several hours) during the climatic conditions prevalent during the observation period, behavior not observed at GS-NW. In practice, it is possible to observe both positive and negative pressure excursions, even during the same fuel delivery (when multiple fuel

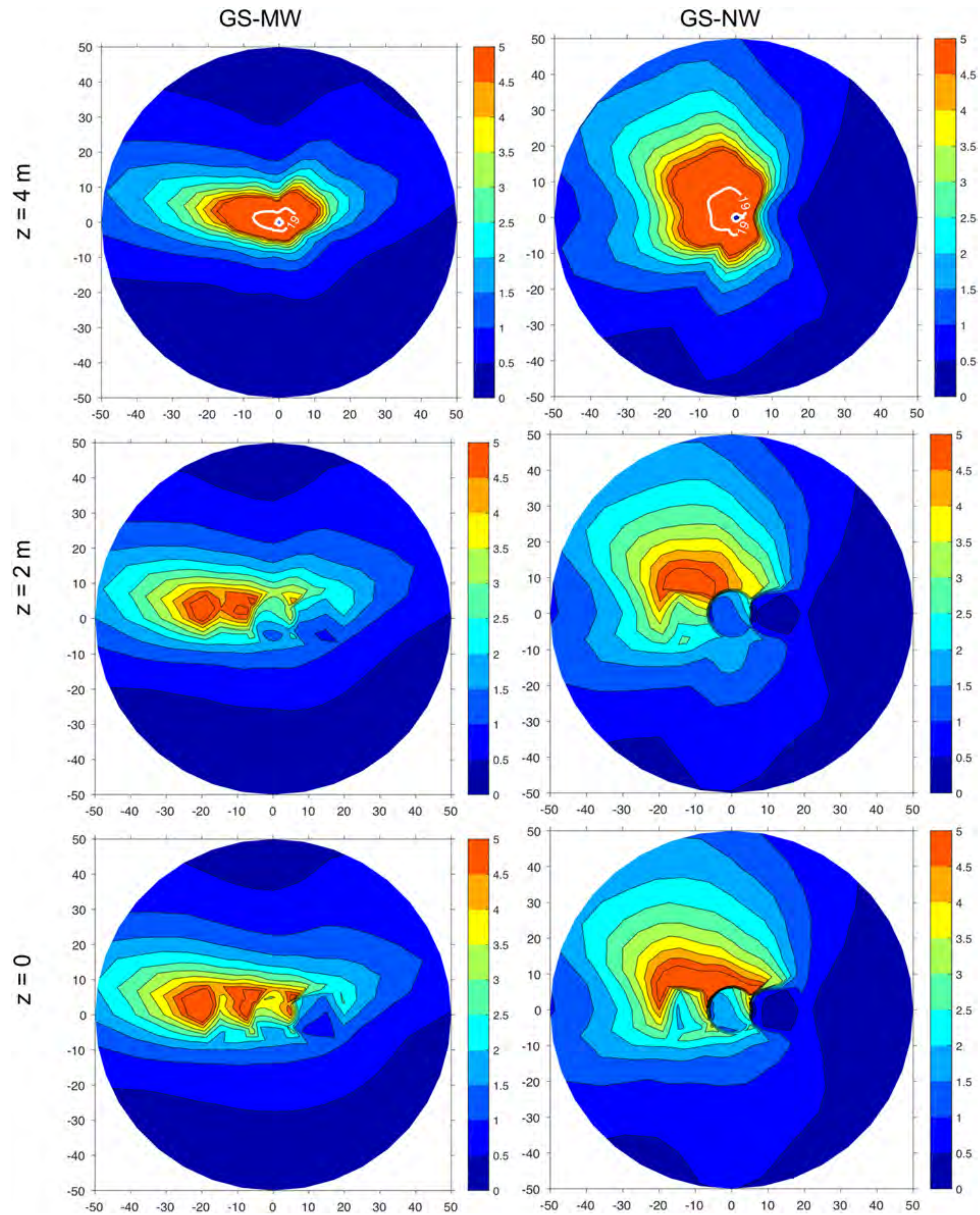

Fig. 6. Modeled average benzene concentrations for GS-MW and GS-NW at three different elevations *z*. The *x*- and *y*-axes indicate horizontal coordinates in meters. The color indicates benzene levels in μg/m^3 and the white isoline the MRL of 19 μg/m^3 = 6 ppb.

compartments of tanker trucks are unloaded), when Stage I vapor recovery is in place (personal observation by TT).

5.5. Exceedance of 1-hour exposure limits

AERMOD air pollution modeling suggests that at GS-MW the 1-hour acute REL was exceeded at one grid point 160 m (525 ft) from the center of the gas station once in 20 days (Fig. 5). This distance is larger than the 300-ft (91 m) setback distance recommended by CARB for a large gasoline dispensing facility (CalEPA/CARB, 2005). Assuming the gas station's fence line is <225 ft. (69 m) from its center (where the vent pipe was assumed to be located), our study shows that sensitive land uses at a distance further than 300 ft from the fence line of the gas station would represent a health concern despite compliance with the CARB guidelines because of non-compliance with the acute REL.

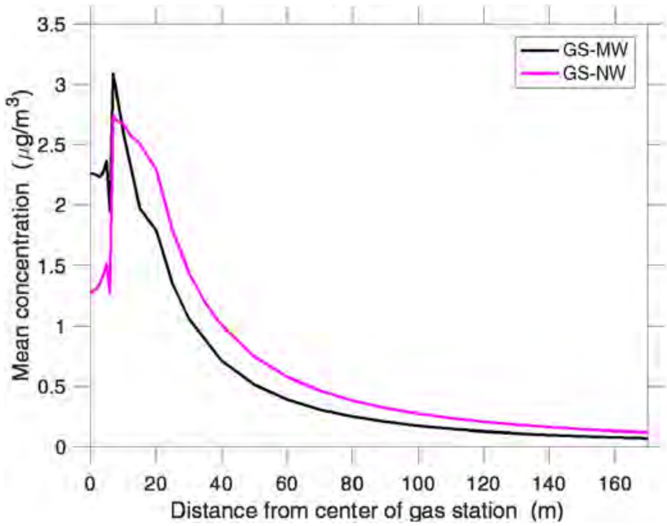

Fig. 7. Mean benzene concentrations as a function of distance from the center of the gas stations.

At any location further than 50 m from the gas station's center, the REL was exceeded at most once during the 20-day measurement campaign (Fig. SI-1a). However, exceedance occurred at several locations, and on two different days (Fig. SI-1b). E.g., at a distance of 120 m from the center, the REL was exceeded at three grid points, and the number of grid points increased with closer proximity to the gas station. This suggests that it was not just a single worst-case scenario or a single accidental vapor release that led to REL exceedance; rather exceedance may occur more frequently than is anticipated. Prevalent wind directions during the measurement campaign explained the directional patterns of exceedances (see the wind rose in Fig. SI-3a).

At GS-NW, despite its higher sales volume, the REL was exceeded only closer than 50 m from the gas station's center. However, exceedance occurred much more frequently (Fig. SI-2), likely because of the higher sales volume of GS-NW. Again, the wind rose for GS-NW (Fig. SI-3b) explains spatial patterns of REL exceedance.

None of AIHA's three ERPG levels were exceeded, meaning that individuals, except perhaps sensitive members of the public, would not have experienced more than mild, transient adverse health effects.

5.6. Average benzene levels

The initial increase in average benzene levels when moving away from the gas stations' centers (Fig. 7) is likely due to the vent emissions (at 4 m) which represent the largest benzene source, and which require a certain transport distance until they reach the 2-m level through dispersion. Further away from the gas station, benzene levels are higher for GS-NW than for GS-MW likely because of the higher sales volume of GS-NW. However, close to the center, benzene levels are higher at GS-MW. This can be attributed to the higher wind speeds at GS-NW (Table SI-1), which result in greater initial dilution of emitted pollutants in the incoming airstream and also in greater subsequent pollutant dispersion.

Modeled average benzene concentrations are generally lower (~10 μg/m^3 or less) than those measured in the surroundings of gas stations, likely because our simulations do not account for traffic-related air pollution (TRAP). For instance, a study published by the Canadian petroleum industry found average benzene concentrations of 146 and 461 ppb (466 and 1473 μg/m^3) at the gas station property boundary in summer and winter, respectively (Akland, 1993), values orders of magnitudes higher than ours. A South Korean study examined outdoor and indoor benzene concentrations at numerous residences within 30 m and between 60 and 100 m of gas stations and found median outdoor benzene concentrations of 9.9 and 6.0 μg/m^3, respectively (Jo & Moon, 1999), while we simulated benzene levels on the order of 1 μg/m^3 (Fig. 7). In a study on atmospheric BTEX levels in an urban area in Iran, the three highest BTEX levels were measured near gas stations (~150 m away); the measured benzene levels (64 ± 36, 31 ± 28, 52 ± 26 μg/m^3) were again much higher than ours simulated at that distance, likely due to TRAP. Our modeled average benzene levels at a distance of about 50 m are on the same order as background benzene levels of 1.0 μg/m^3 that were measured in 2010 in the National Air Toxics Trend Sites (NATTS) network of 27 stations located in most major urban areas in the US (Strum & Scheffe, 2016). However, our modeled levels at a distance of 170 m were 0.07 at GS-MW and 0.12 at GS-NW, a non-negligible addition to urban background levels.

At both gas stations, the MRL was exceeded at the level of the vent pipe opening in the vicinity of the gas stations, up to 7 m away from the vent pipe at GS-MW and 8 m at GS-NW. Therefore there might be an appreciable risk of adverse noncancer health effects for individuals living at the 2nd-floor level relatively close to high-volume gas stations such as GS-MW and GS-NW.

5.7. Limitations

A limitation of our study is that data were collected only in fall and winter. Results cannot be easily extrapolated to other seasons, because vent pipe emissions are seasonally dependent, e.g., due to seasonally dependent gasoline formulations and meteorological conditions. However, modeled exceedance of the OEHHA acute REL in the winter season is already of concern, because that REL was developed for once per month or less exposures.

Another limitation is that we did not directly measure benzene levels in the vent pipe, and instead made assumptions about vapor composition that were also made in the CAPCOA study (CAPCOA, 1997) of gas station emissions. In practice it may be difficult to obtain permission from gas station owners to measure benzene levels directly.

In part because we did not want to reveal the locations of the gas stations, we did not use site-specific topography information in the air dispersion modeling and instead assumed flat terrain. While this simplification results in less accurate air pollution predictions for the two sites, using a "generic" gas station is perhaps more representative of other gas station sites, and is consistent with an approach used in a previous study (CAPCOA, 1997).

Finally, our study did not predict benzene levels in indoor environments. Even though indoor air pollution levels may substantially differ from outdoor levels due to indoor sources (e.g., smoking, photocopying) (El-Hashemy & Ali, 2018), our study can still inform exposure levels in indoor environments as outdoor sources may be the main contributors to indoor air pollution, e.g., in buildings situated in urban areas and close to industrial zones or streets with heavy traffic (Jones, 1999). This is relevant to workers and customers in C-stores or other fast-food/gasoline station combination facilities.

6. Conclusions

Our study is to the best of our knowledge the first one to (1) report hourly vent emission data for gasoline storage tanks in the peer-reviewed literature and (2) use these data in hourly simulations of atmospheric benzene vapor transport. This allowed us to examine potential exceedance of short-term exposure limits for benzene. Prior studies including CAPCOA's (CAPCOA, 1997) could not do so as average emission rates were used (only meteorological data was used at an hourly resolution).

Our findings support the need to revisit setback distances for gas stations, which are based on >2-decade old estimates of vent emissions (Aerovironment, 1994). Also, CARB setback distances are based on a binary decision, related to whether the gasoline sales volume $\dot{V}_{sales}$ is >3.6 million gal per year. Our data support, however, that setback distances should be a continuous function of sales volume $\dot{V}_{sales}$ and also include the type of controls installed at the facility. Setback distances should also address health outcomes other than cancer. OEHHA's acute REL for benzene could be used to inform setback distances as it accounts for non-cancer adverse health effects of benzene and its metabolites (Budroe, 2014). ATSDR's MRL could also be considered since it is a health-based limit.

We note that CARB recommended their setback distances in 2005, presumably assuming pollution prevention technology yielding a 90% reduction in benzene emissions (CalEPA/CARB, 2005). Since then, CARB further promoted use of second-generation vapor recovery technology (Enhanced Vapor Recovery, EVR) to reduce emissions further. EVR includes technology that is supposed to prevent fuel vapors in overpressurized tanks from being expelled into the atmosphere (CARB, 2017). To that end, "bladder tanks" have been proposed, into which the gasoline vapor/air mixture is directed as the pressure in the combined ullage space of the storage tank increases, and from which the mixture is redirected into the fuel storage tanks if the ullage pressure becomes negative (when fuel is dispensed). The challenge with such a system is to ensure that the bladder tank capacity is not exceeded by the fuel evaporation rate. Alternatively, fuel vapor release can be reduced by processing the fuel/air mixture through either a semi-permeable membrane which selectively exhausts clean air and returns enriched fuel vapor (Semenova, 2004) or an activated carbon filter which adsorbs hydrocarbons (and water vapor) and exhausts air into the atmosphere, or by combusting the fuel/air mixture which would otherwise be released through the P/V valve. Therefore, current CARB setback distances might be adequate for gas stations in California but less so for the other 49 US states, and other countries—depending on pollution prevention technology requirements.

The larger areal extent of modeled REL exceedance at GS-MW is due to "accidental" releases of gasoline vapors. Even though regulations appear generally not to be driven by accidental releases, at GS-NW such releases likely led on two different days to REL exceedances at distances beyond CARB's recommended setback distances. Policies should address accidental fuel vapor releases that depending on pollution prevention technology (here Stage I vapor recovery) and its proper functioning can occur on a frequent basis (twice at GS-MW within about three weeks).

In future work, potential exceedance of other shorter-term exposure limits should be examined, e.g., the 15-minute short-term exposure limits (STELs) and the 8-hour time-weighted averages (TWAs) used for occupational exposures.

Acknowledgements

This work was supported by NIH grant P30 ES009089 and the Environment, Energy, Sustainability and Health Institute at Johns Hopkins University.

Competing financial interest declaration

TT directs a company (ARID), which develops technologies for reducing fuel emissions from gasoline-handling operations. AMR, BAM and MH have no conflicts of interests to declare.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.scitotenv.2018.09.303.

References

Adria-Mora, B., Hilpert, M., 2017. Differences in infiltration and evaporation of diesel and gasoline droplets spilled onto concrete pavement. Sustainability 9 (7). https://doi.org/10.3390/su9071271.

Aerovironment, 1994. I. Underground Storage Tank Vent Line Emissions form Retail Gasoline Outlets. Prepared for WSPA (AV-FR-92-01-204R2).

AIHA, 2016. ERPG/WEEL Handbook. Current ERPG® Values (2016). American Industrial Hygiene Association, p. 2016.

Akland, G.G., 1993. Exposure of the general population to gasoline. Environ. Health Perspect. 101 (Suppl. 6), 27–32 (Epub 1993/12/01. PubMed PMID: 8020446; PMCID: PMC1520004).

Atabi, F., Mirzahosseini, S.A., 2013. GIS-based assessment of cancer risk due to benzene in Tehran ambient air. Int. J. Occup. Med. Environ. Health 26 (5), 770–779. https://doi.org/10.2478/s13382-013-0157-4 (Epub 2014/01/28, PubMed PMID: 24464541).

ATSDR, 2004. Interaction Profile for: Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX). Agency for Toxic Substances and Disease Registry.

ATSDR, 2007. Toxicological Profile for Benzene. Agency for Toxic Substances and Disease Registry (CAS#: 71-43-2).

ATSDR, 2018. Minimal Risk Levels (MRLs): Agency for Toxic Substances and Disease Registry. Available from: https://www.atsdr.cdc.gov/mrls/index.asp (May 24, 2018).

Brosselin, P., Rudant, J., Orsi, L., Leverger, G., Baruchel, A., Bertrand, Y., et al., 2009. Acute childhood leukaemia and residence next to petrol stations and automotive repair garages: the ESCALE study (SFCE). Occup. Environ. Med. 66 (9), 598–606.

Budroe, J., 2014. Notice of adoption of revised reference exposure levels for benzene: Office of Environmental Health Hazard Assessment (California, US). Available from: https://oehha.ca.gov/air/crnr/notice-adoption-revised-reference-exposure-levels-benzene.

CalEPA/CARB, 2005. Air Quality and Land Use Handbook: A Community Health Perspective: California Environmental Protection Agency & California Air Resources Board.

CAPCOA, 1997. Gasoline Service Station Industrywide Risk Assessment Guidelines. Toxics Committee of the California Air Pollution Control Officers Association (CAPCOA).

CARB, 2013. Revised Emission Factors for Gasoline Marketing Operations at California Gasoline Dispensing Facilities. California Air Resources Board, Monitoring and Laboratory Division.

CARB, 2017. Public workshop to discuss: overpressure conditions at gasoline dispensing facilities equipped with underground storage tanks and phase ii enhanced vapor recovery including in-station diagnostic systems. December 12–13, 2017 Diamond Bar & Sacramento, CA California Air Resources Board. Available from: https://www.arb.ca.gov/vapor/op/wrkshps/dec2017op_vr_pres.pdf.

Cimorelli, A.J., Perry, S.G., Venkatram, A., Weil, J.C., Paine, R.J., Wilson, R.B., et al., 2005. AERMOD: a dispersion model for industrial source applications. Part I: general model formulation and boundary layer characterization. J. Appl. Meteorol. 44 (5), 682–693.

Correa, S.M., Arbilla, G., Marques, M.R.C., Oliveira, K.M.P.G., 2012. The impact of BTEX emissions from gas stations into the atmosphere. Atmos. Pollut. Res. 3 (2), 163–169.

Cruz, L., Alves, L., Santos, A., Esteves, M., Gomes, Í., Nunes, L., 2007. Assessment of BTEX concentrations in air ambient of gas stations using passive sampling and the health risks for workers. J. Environ. Prot. 8, 12–25.

Cruz-Nunez, X., Hernandez-Solis, J.M., Ruiz-Suarez, L.G., 2003. Evaluation of vapor recovery systems efficiency and personal exposure in service stations in Mexico City. Sci. Total Environ. 309 (1–3), 59–68. https://doi.org/10.1016/s0048-9697(03)00048-2.

Edokpolo, B., Yu, Q.J., Connell, D., 2014. Health risk assessment of ambient air concentrations of benzene, toluene and xylene (BTX) in service station environments. Int. J. Environ. Res. Public Health 11 (6), 6354–6374 (PubMed PMID: PMC4078583).

Edokpolo, B., Yu, Q.J., Connell, D., 2015. Health risk characterization for exposure to benzene in service stations and petroleum refineries environments using human adverse response data. Toxicol. Rep. 2, 917–927.

EIA, 2017. U.S. product supplied of finished motor gasoline: U.S. Energy Information Administration. Available from: http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=pet&s=mgfupus1&f=m.

El-Hashemy, M.A., Ali, H.M., 2018. Characterization of BTEX group of VOCs and inhalation risks in indoor microenvironments at small enterprises. Sci. Total Environ. 645, 974–983.

EPA, 2004. Stage II Vapor Recovery Systems Issues Paper. U.S. EPA. Office of Air Quality Planning and Standards. Emissions Monitoring and Analysis Division. Emissions Factors and Policy Applications Group (D243-02).

EPA, 2008. Transportation and marketing of petroleum liquids. Environmental Protection Agency. Petroleum Industry vol. I (Chapter V, AP 42).

Hajizadeh, Y., Mokhtari, M., Faraji, M., Mohammadi, A., Nemati, S., Ghanbari, R., et al., 2018. Trends of BTEX in the central urban area of Iran: a preliminary study of photochemical ozone pollution and health risk assessment. Atmos. Pollut. Res. 9 (2), 220–229.

Harrison, R.M., Leung, P.L., Somervaille, L., Smith, R., Gilman, E., 1999. Analysis of incidence of childhood cancer in the West Midlands of the United Kingdom in relation to proximity to main roads and petrol stations. Occup. Environ. Med. 56 (11), 774–780.

Hilpert, M., Breysse, P.N., 2014. Infiltration and evaporation of small hydrocarbon spills at gas stations. J. Contam. Hydrol. 170, 39–52.

Hilpert, M., Mora, B.A., Ni, J., Rule, A.M., Nachman, K.E., 2015. Hydrocarbon release during fuel storage and transfer at gas stations: environmental and health effects. Curr. Environ. Health Rep. 2 (4), 412–422. https://doi.org/10.1007/s40572-015-0074-8.

IARC, 2012. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans. vol. 100F Available from:. http://monographs.iarc.fr/ENG/Monographs/vol100F/ (December 24, 2017).

Infante, P.F., 2017. Residential proximity to gasoline stations and risk of childhood leukemia. Am. J. Epidemiol. 185 (1), 1–4.

Jo, W.K., Moon, K.C., 1999. Housewives' exposure to volatile organic compounds relative to proximity to roadside service stations. Atmos. Environ. 33 (18), 2921–2928. https://doi.org/10.1016/s1352-2310(99)00097-7.

Jo, W.K., Oh, J.W., 2001. Exposure to methyl tertiary butyl ether and benzene in close proximity to service stations. J. Air Waste Manage. Assoc. 51 (8), 1122–1128. https://doi.org/10.1080/10473289.2001.10464339.

Attachment "F"

Jones, A.P., 1999. Indoor air quality and health. Atmos. Environ. 33 (28), 4535–4564.

Karakitsios, S.P., Delis, V.K., Kassomenos, P.A., Pilidis, G.A., 2007. Contribution to ambient benzene concentrations in the vicinity of petrol stations: estimation of the associated health risk. Atmos. Environ. 41 (9), 1889–1902.

McEntire, B.R., 2000. Performance of Balance Vapor Recovery Systems at Gasoline Dispensing Facilities. San Diego Air Pollution Control District.

Morgester, J.J., Fricker, R.L., Jordan, G.H., 1992. Comparison of spill frequencies and amounts at vapor recovery and conventional service stations in California. J. Air Waste Manage. Assoc. 42 (3), 284–289.

Semenova, S.I., 2004. Polymer membranes for hydrocarbon separation and removal. J. Membr. Sci. 231 (1–2), 189–207.

Statistics Canada, 2009. Gasoline evaporative losses from retail gasoline outlets across Canada: environment accounts and statistics analytical and technical paper series. Available from: http://www.statcan.gc.ca/pub/16-001-m/2012015/part-partie1-eng.htm.

Steffen, C., Auclerc, M.F., Auvrignon, A., Baruchel, A., Kebaili, K., Lambilliotte, A., et al., 2004. Acute childhood leukaemia and environmental exposure to potential sources of benzene and other hydrocarbons; a case-control study. Occup. Environ. Med. 61 (9), 773–778. https://doi.org/10.1136/oem.2003.010868.

Strum, M., Scheffe, R., 2016. National review of ambient air toxics observations. J. Air Waste Manage. Assoc. 66 (2), 120–133. https://doi.org/10.1080/10962247.2015.1076538 (1995, PubMed PMID: 26230369, Epub 2015/08/01).

Terres, I.M.M., Minarro, M.D., Ferradas, E.G., Caracena, A.B., Rico, J.B., 2010. Assessing the impact of petrol stations on their immediate surroundings. J. Environ. Manag. 91 (12), 2754–2762. https://doi.org/10.1016/j.jenvman.2010.08.009.

WHO, 2010. WHO Guidelines for Indoor Air Quality: Selected Pollutants. World Health Organization, Geneva.

Yerushalmi, L., Rastan, S., 2014. Evaporative losses from retail gasoline outlets and their potential impact on ambient and indoor air quality. In: Li, A., Zhu, Y., Li, Y. (Eds.), Proceedings of the 8th International Symposium on Heating, Ventilation and Air Conditioning. Indoor and Outdoor Environment Vol. 1. Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 13–21.

Attachment "F"

2020 Study
Gasoline Vapor Emissions During Vehicle Refueling Events in a Vehicle Fleet Saturated With Onboard Refueling Vapor Recovery Systems - Need for an Exposure Assessment

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Attachment "F"

BRIEF RESEARCH REPORT
published: 07 February 2020
doi: 10.3389/fpubh.2020.00018

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Gasoline Vapor Emissions During Vehicle Refueling Events in a Vehicle Fleet Saturated With Onboard Refueling Vapor Recovery Systems: Need for an Exposure Assessment

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OPEN ACCESS

Edited by:
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Reviewed by:
Yue-Wern Huang, Missouri University of Science and Technology, United States
Rich Baldauf, United States Environmental Protection Agency, United States

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Specialty section:
This article was submitted to Environmental Health, a section of the journal Frontiers in Public Health

Received: 30 August 2019
Accepted: 20 January 2020
Published: 07 February 2020

Citation:
Shearston JA and Hilpert M (2020) Gasoline Vapor Emissions During Vehicle Refueling Events in a Vehicle Fleet Saturated With Onboard Refueling Vapor Recovery Systems: Need for an Exposure Assessment. Front. Public Health 8:18. doi: 10.3389/fpubh.2020.00018

Background: Gasoline contains large proportions of harmful chemicals, which can be released during vehicle refueling. Onboard Refueling Vapor Recovery (ORVR) can reduce these emissions, but there is limited research on the system's efficacy over time in an actual vehicle fleet. The aims of this study are: (1) determine the feasibility of using an infrared camera to view vapor emissions from refueling; (2) examine the magnitude of refueling-related emissions in an ORVR-saturated fleet, to determine need for an exposure-assessment.

Methods: Using an infrared camera optimized for optical gas imaging of volatile organic chemicals, refueling was recorded for 16 vehicles at six gas stations. Pumps were inspected for damage, refueling shut-off valve functioning, and presence of Stage II Vapor Recovery. Vehicle make/model and age were recorded or estimated.

Results: Vapor emissions were observed for 14 of 16 vehicles at each station, with severity varying substantially by vehicle make/model and age. Use of an infrared camera allowed for identification of vapor sources and timing of release, and for visualizing vapor trajectories.

Discussion: Notably emissions occurred not only at the beginning and end of refueling but also throughout, in contrast to a prior study which did not detect increases in atmospheric hydrocarbon levels mid-refueling. Future studies are vitally needed to determine the risk to individuals during typical refueling in an ORVR saturated vehicle fleet. We recommend comprehensive exposure-assessment including real-time monitoring of emitted volatile organic compounds paired with infrared gas-imaging and measurement of internal dose and health effects of gas station customers.

Keywords: gasoline, environmental exposure, vehicle refueling, volatile organic compounds, gas station

INTRODUCTION

Gasoline is a complex mixture of many chemicals, several of which are known to adversely affect human health. Of particular concern are volatile aromatic hydrocarbons, including benzene, toluene, ethylbenzene, and xylene (BTEX group), which may be released during vehicle refueling (1, 2). For example, benzene is a known human carcinogen and is associated with multiple health problems, including respiratory, nervous system, and immunological conditions (3). In addition, studies evaluating non-cancer outcomes have found decreased red blood cell counts, hemoglobin, and hematocrit levels in gas station attendants (4). While some studies have evaluated exposures to gasoline from vehicle refueling specifically (5–7), to our knowledge, few have been completed in the past decade. It is essential that such studies are repeated frequently and in varied geographic locations, as fuel composition, weather, climate, and pollution control strategies all impact individual exposures and can change over time.

In the United States (US), changes in regulations outlining gasoline vapor recovery during vehicle refueling have made this an especially pressing question. During refueling, gasoline vapor in a vehicle's tank is pushed into the atmosphere by the rising liquid gasoline level in the tank—unless a vapor recovery system is in place. From 1998 to 2006, the US Environmental Protection Agency (EPA) rolled out a requirement that nearly all newly manufactured vehicles be equipped with onboard refueling vapor recovery (ORVR) systems (8), which function by directing vaporized gasoline into a canister on the vehicle, thereby substantially reducing escape of vapors into the atmosphere. Briefly, this requirement was rolled out in stages, first for light duty vehicles (1998: 40% of new vehicles, 1999: 80%, 2000: 100%), then for light duty trucks and vans (2001: 40%, 2002: 80%, 2003: 100%), and finally for heavier light duty trucks (2004: 40%, 2005: 80%, 2006: 100%) and trucks with a >10,000 pounds gross vehicle weight rating (100% by 2006). By 2006, nearly all new gas-powered vehicles with <14,000 pound gross vehicle weight rating were required to have ORVR systems (8). In contrast, Stage II vapor recovery systems, which are used on gasoline pumps themselves, direct vaporized gasoline into gas station underground storage tanks through systems on the pumps. In 2012, the EPA determined that the US vehicle fleet was sufficiently saturated with ORVR that states could allow the removal of Stage II systems (8), thus making vapor recovery during refueling primarily dependent on ORVR systems.

Despite this change in regulations, limited information on the efficiency of ORVR systems is available, although the US EPA suggests they are 98% efficient and require minimal maintenance (8). A German study found no measurable increases in atmospheric hydrocarbon concentrations in a Sealed Housing for Emissions Determination (SHED) in which an ORVR-equipped vehicle was placed during refueling, although increases were detected at the beginning and end of refueling (9). Even though a study of presumably non-ORVR equipped vehicles in Mexico found older vehicles to have more evaporative emissions than newer ones (10), to the best of our knowledge, no assessment of the continuous functioning of ORVR systems to reduce emissions during vehicle refueling over the course of a vehicle's lifetime, within the conditions of an actual vehicle fleet, has been completed. It is possible that as vehicles age, hoses, seals, and other parts of the gas tank and ORVR system degrade, resulting in increased vapor emissions during refueling. Additionally, while some studies (6, 7) evaluated exposure to gasoline vapors during vehicle refueling in the US, finding evidence of benzene in blood and exhaled breath samples, those studies were completed before saturation of the US vehicle fleet with ORVR systems, and are thus likely over-estimates of exposures that may occur with ORVR systems. It is not currently known whether the amount of vapors today's population is exposed to would have similar, if any, effects.

Past studies assessing exposure from vehicle refueling used aluminum tubes as passive samplers (7) and sorbent tubes attached to pumps (6) to quantify exposure to gasoline vapors, positioned in the breathing zone of participants. However, such methods may not be able to detect the lower levels of exposure anticipated from a vehicle fleet with a 98% efficient ORVR system. Additionally, while these methods quantify environmental exposure to vapors during refueling, they are not easily used for source identification or to capture the dispersion and movement of vapors at the station. It is also not possible to use these devices to determine when during a refueling event vapors are more likely to be released (i.e., at the end vs. throughout), information which can help determine the cause of vapor release. Use of other technologies, such as an infrared camera optimized for visualizing compounds present in petroleum products, is needed to determine the sources of vapors during refueling (i.e., from exhaust, the vehicle tank, or the pump nozzle) and how they move through space. Such cameras are also fine-tuned to detect very small amounts of vapors, and thus may be invaluable in determining if exposure to gasoline vapors is occurring from ORVR equipped vehicles, warranting a more involved exposure-assessment.

Research on the functioning of ORVR in the actual US vehicle fleet over time, and thus an understanding of the quantity of vapors individuals may still be exposed to, is limited. Additionally, the tools traditionally used to assess exposure to vapors during vehicle refueling do not give a complete picture, as they lack the ability to determine vapor sources and movement. With this pilot study, we aim to determine the plausibility and usefulness of conducting a full exposure-assessment for exposures to gasoline vapors during vehicle refueling, in a vehicle fleet dependent on ORVR for vapor recovery. The objectives of this pilot study are to (1) determine the feasibility of qualitatively capturing fuel vapor emissions from vehicle refueling events in New York City (NYC) using a FLIR infrared camera designed specifically to detect volatile organic compounds present in petroleum products, and to (2) examine the magnitude of fuel vapor emissions over a range of different vehicle/ORVR system ages as a precursor to assessing the continuous functioning of ORVR systems over the lifetime of a vehicle in the actual US vehicle fleet.

MATERIALS AND METHODS

Study Overview

A convenience sample of gas stations in Northern Manhattan, NYC, was selected for vapor release monitoring. At each gas station, a study member approached individuals just before they began refueling their vehicles and asked for verbal permission to record their vehicle tanks as the vehicle was refueled. This study is not human subjects research, as no information about individuals was obtained, and is thus not subject to IRB oversight.

A total of six gas stations were visited over the course of a single winter day. Three vehicle refueling events were recorded at each station, with the exception of one station where an attendant was present. For this station, only one vehicle refueling event was recorded. In total, $n = 16$ refueling events were recorded.

Data Collection

An infrared camera optimized for optical gas imaging of volatile organic chemicals (FLIR model GF320; described below) and frequently used to detect leaks in petroleum refining operations, was used to record the fuel pump nozzle and external vehicle fuel tank filler pipe during each refueling session. In addition, researchers visually inspected gasoline pumps for hose damage, refueling shut-off valve functioning, and presence of Stage II Vapor Recovery systems. Researchers recorded the make and model of the vehicle when it was visible on the outside of the automobile, while year was estimated using photographs of the vehicle. Year was estimated by searching for images of the vehicle make and model, and comparing different years, especially the front and rear bumpers and headlight shape, to those shown in the photographs. When researchers could not definitively determine the year of the vehicle, the midpoint of the plausible year range was used. Vehicles were assigned a type based on the EPA Vehicle Classification system.

Overview of FLIR Infrared Camera

The FLIR model GF320 infrared camera can detect 20 gases, including: 1-pentene, benzene, butane, ethane, ethanol, ethylbenzene, ethylene, heptane, hexane, isoprene, m-xylene, methane, methanol, methyl ethyl ketone, MIBK, octane, pentane, propane, propylene, and toluene (FLIR Systems Inc., 2017). The camera is tuned to detect very small spectral ranges, so that it can selectively visualize specific compounds that absorb or emit electromagnetic energy at that spectral range. A narrow bandpass filter is used to ensure that only gases with a strong signal in the specified infrared range are detected, and other components of the camera are built to emit very little energy, to reduce the signal-to-noise ratio. The manufacturer does not provide estimates of limits of detection of their camera, but we found that the GF320 can detect quite small vapor leakage rates, e.g., gas emissions from an unignited pocket lighter in outdoor atmospheric environments imaged from a distance of at least 2 m.

Qualitative and Statistical Analysis

To determine how representative our convenience sample is of New York State and New York City vehicle fleet ORVR saturation, we used New York State's publicly available Vehicle, Snowmobile, and Boat Registrations database to calculate the proportion of registered vehicles in both the state and city that were gasoline powered and manufactured in 2006 or later (out of all gasoline powered vehicles), the year the EPA suggests that "essentially all" new gas-powered vehicles $<$14,000 pounds were manufactured with ORVR systems (8). We compared this to the proportion of ORVR equipped vehicles in our sample. In addition, we compared the median vehicle manufacturing age in our sample to that of registered vehicles in New York State and City.

Each infrared video was reviewed to identify the presence and magnitude of vaporized gasoline emitted during a refueling session. An overall qualitative description of each video was created, and patterns of vapor emission were identified and assigned to each session. Vapor origin (i.e., ambient vapors vs. vapors from the vehicle fuel tank) and the timing of vapor release was reviewed in all sessions. Representative video frames of "typical" emissions for each vehicle were extracted from the middle and end of each refueling session. The vapor plume was delineated using the brush feature in Microsoft Paint based on repeated observations of the videos, and not just a single frame, as it is difficult to identify the plume from a static image.

Exploratory statistical analysis was conducted in R version 3.5.1 (11). A logistic model was fit to obtain an association between estimated vehicle age and presence of vapor release during the middle of vehicle refueling, operationalized as a binary variable. Due to the small sample size no covariates were included in the model.

Figures were created with the tidyverse package in R (12), as well as with Inkscape (www.inkscape.org) and MATLAB (The MathWorks Inc., 2010).

RESULTS

A total of 16 refueling events at six gas stations were recorded. Our convenience sample was fairly representative of the estimated ORVR penetration proportion in New York State and City vehicles: according to EPA regulations 94% of our sample should have been equipped with ORVR, while for both New York State and City, we estimate that at least 81% of registered vehicles should have been equipped with ORVR. The median manufacturing year of our sample was 2013, the same as that for New York State and City.

Table 1 provides details about gas stations and vehicles. Of the six stations, only one had a Stage II vapor recovery system, and four had liquid gasoline leaking around the hose joints. Estimated vehicle age ranged from 1 to 32 years (manufacturing years 1987–2018), and several vehicle types (e.g., SUV, mid-size car) were represented in the sample. For 15 out of 16 vehicles, vehicle age and type combination indicated they were required to contain ORVR systems. The average refueling length was 86 s. Ambient temperature ranged from 33 to 41°F (0.5–5°C).

The infrared camera was able to detect gasoline vapors during vehicle refueling. In addition, evaluation of the video files allowed researchers to identify vapor sources, pinpoint the time of vapor release during each video, and to see how the vapors moved after being emitted.

TABLE 1 | Characteristics of gas stations and vehicle refueling events.

Gas station ID	Stage II vapor recovery system	Hose joints	Vehicle ID	EPA vehicle size classification	Estimated model year	ORVR mandate*	Length of refueling (s)
2	None	No leakage	29	Minicompact car	2014	Yes	66
			30	Midsize car	2005	Yes	88
			32	Standard sport utility vehicle	2013	Yes	88
3	None	Leakage	33	Midsize car	2006	Yes	76
			34	Mid-size car	2018	Yes	78
			35	Small sport utility vehicle	2013	Yes	84
4	None	Leakage	36	Mid-size car	2008	Yes	131
			37	Standard sport utility vehicle	2018	Yes	133
			38	Standard sport utility vehicle	2015	Yes	71
8	Vacuum assist	Leakage	41	Compact car	2005	Yes	72
			42	Midsize car	2016	Yes	122
			43	Midsize car	2008	Yes	66
9	None	Leakage	44	Standard sport utility vehicle	2004	Yes	56
			45	Large car	1987	No	110
			46	Midsize car	2015	Yes	106
7	None	No leakage	47	Minivan	2013	Yes	32

**Indicates whether 100% of new vehicles were required to have included ORVR systems for the specific manufacturing year and vehicle type (i.e., light duty vehicle, light duty truck, and van, heavier light duty trucks, etc.).*

Fuel vapor emissions were observed for 14 out of 16 vehicles and at every gas station. The single vehicle older than ORVR manufacturing mandates in the US clearly had much larger refueling vapor emissions than the newer vehicles. However, the majority of newer vehicles also had substantial fuel vapor emissions, particularly at the end of refueling. Qualitative descriptions of each refueling event are provided in **Table 2**. Six overall patterns of vapor emission were identified: no vapor release (one vehicle), ambient vapors only (one vehicle), release toward the end of refueling (two vehicles), release when nozzle was withdrawn (three vehicles), release toward the end of refueling and after nozzle was withdrawn (six vehicles), and near continuous vapor release (three vehicles). **Figure 1** shows the number of vehicles in each category, and the years of the vehicles' manufacture. The three vehicles with near continuous vapor release were estimated to be 5, 11, and 32 years old. Of note, all vehicles that emitted vapors at any point during the refueling session also did so at the end of the refueling session.

Representative video frames from the middle and end of each refueling session are available in the **Supplementary Material** (two frames per vehicle). In **Figure 2**, examples from each of the six vapor emission patterns are shown, with gasoline vapor plumes delineated in blue in each frame, and vehicle IDs in the top right corner. For example, for the "release when nozzle withdrawn" category, the representative screenshot during the middle of the refueling session does not show any vapors, however, at the end of the session, vapors can be seen spilling out around the pump nozzle and the vehicle fuel tank opening. The range of emission magnitude can be seen from the various sample frames. Full video recordings for each refueling event are available at the following link: https://github.com/jenni-shearston/Vehicle_Refueling_Videos.

Results from the exploratory logistic regression were not significant, as there were not enough observations to detect an association ($n = 16$; yes release [$n = 3$]/no release [$n = 13$]). The model suggested that a 1 year increase in estimated vehicle age was associated with a 1.15 increase in likelihood of emitting vapors during the middle of refueling (95% CI = 0.97, 1.51), but this result is likely driven by the results for the 32 years old vehicle, which was much older than the rest of the vehicle population.

DISCUSSION

This work highlights the value of using an infrared camera to compliment more traditional methods of exposure measurement for determining potential health risks from vehicle refueling, and visually highlights the sometimes large amounts of fuel vapor emissions that occur even within an ORVR saturated vehicle fleet.

A FLIR camera allowed us to identify the source of the vapors; for example, in one video (Vehicle ID 44) vapors can be seen, but they do not originate from the pump nozzle or the vehicle tank. Of note, we observed leaking gasoline around the hose joints at this station (Station 9). For all other videos, vapors are clearly seen coming out of the pump nozzle, vehicle tank, or both. This allows for the differentiation of sources of vapor exposure, crucial information needed to intervene on exposures at gas stations generally, or to determine how effective ORVR is at minimizing vapor outflow. In addition, use of the infrared camera allowed us to confirm that vapors were emitted in a location where an individual filling up their gas tank might breathe them in (the "breathing zone"), and to visualize the dispersion and movement of the vapors. The infrared camera also made it possible to pinpoint when during a refueling session

TABLE 2 | Qualitative description and overall patterns of vehicle refueling events.

Vehicle ID	Qualitative description	Overall pattern
29	Some gasoline vapor can be seen escaping into the atmosphere from the beginning of the refueling event, continuing throughout the duration of refueling. At around 0:00:41, a larger amount of vapor is seen escaping from the vehicle tank, generally increasing in amount until the end of the refueling session	Near continuous vapor release
30	No vapors are seen escaping into the atmosphere until more than a minute of refueling has passed (0:01:13), after which a large amount of vapor escapes as the vehicle tank presumably reaches full	Release toward end of refueling
32	Minimal vapor was released into the atmosphere throughout the duration of the refueling event. At the very end of refueling, as the pump is removed from the tank, a small amount of vapor can be seen escaping	Release toward end of refueling and after nozzle withdrawn
33	No vapors are seen escaping from the vehicle tank until the end of refueling, around 0:01:13, after which a large amount of vapor escapes, presumably as the tank reaches full. After the pump is withdrawn from the tank, fuel vapor continues to escape into the atmosphere in substantial quantities	Release toward end of refueling and after nozzle withdrawn
34	No vapor is seen escaping until the end of the refueling session, around 0:01:11, after which a substantial amount of fuel escapes into the atmosphere, continuing to escape even after the pump is withdrawn from the vehicle	Release toward end of refueling and after nozzle withdrawn
35	No vapor is seen escaping from the vehicle tank until the end of refueling. Vapors escape when the pump handle is partially withdrawn (0:01:12) and the tank is presumably topped off, and continue to escape even after the pump is fully withdrawn	Release toward end of refueling and after nozzle withdrawn
36	Although the pump is inserted into the vehicle from the beginning of the video, it appears that fuel is not dispensed until around 0:00:43 when the individual's hand squeezes the pump handle. As dispensing begins, large amounts of vapors can be seen escaping from the tank. Of note, the individual refueling does not fully insert the pump into the tank. Vapors escape nearly continuously throughout refueling, sometimes in large amounts. Toward the end of the session another large amount of vapor escapes, as the pump is pulled further out of the vehicle (0:01:55). Substantial amounts of vapor continue to escape until the end of refueling, including after the pump is fully withdrawn (0:02:49)	Near continuous vapor release
37	No vapor release observed	No vapor release
38	No vapor is observed until around 0:00:51, after which vapor is released nearly continuously. Vapor is observed escaping from the tank after the pump is withdrawn	Release toward end of refueling and after nozzle withdrawn
41	Some vapor is released at the beginning of the refueling session (0:00:14), but no more is observed until toward the end of refueling around (0:01:08). After this time, vapor is observed in substantial quantities until the pump is withdrawn (0:01:21), after which only minimal vapors are observed escaping	Release toward end of refueling
42	No vapors are observed until the very end of refueling, when the pump is withdrawn (0:01:59). Vapor continues to be released from the tank until it is capped	Release when nozzle withdrawn
43	No vapor release observed during refueling; a small amount of vapor may be released after pump is withdrawn (0:01:08)	Release when nozzle withdrawn
44	Poor video focus makes vapor observation difficult; however, ambient vapors appear to be present (upper right, 0:00:35, 0:00:40, 0:00:54)	Ambient vapors only
45	Substantial vapor release observed as cap is removed from tank, and continuously throughout refueling	Near continuous vapor release
46	No vapor release observed during refueling; a slight amount of release from pump observed as it was removed from tank (0:01:57)	Release when nozzle withdrawn
47	Slight amount of vapor release observed at start of refueling (0:00:03), and then again at end of refueling (0:00:24). Vapor continues to be released after pump removed	Release toward end of refueling and after nozzle withdrawn

vapors were released. Sorbent tubes attached to pumps, passive samplers, and real-time monitors are not able to do this because the amount of vapor measured is averaged over a time period, so it is challenging to determine when the vapor is released, or if it is released continuously.

Information about the timing of vapor releases is particularly useful because it can help researchers determine why vapors are being released. For example, ORVR systems with "liquid seals" are known to release some vapors at the end of refueling (13), because as the flow of gasoline into the vehicle tank decreases, the air gradient into the tank created by the moving gasoline decreases, allowing vapors to flow both into the tank and out of it (and thus into the atmosphere) (9). Release at the end of vehicle refueling was indeed one of our most common observations. However, vapor releases occurring in the middle of the refueling session, or throughout the session, both of which we observed in multiple refueling events, may suggest a breakdown in functioning of the ORVR system. These findings appear to be inconsistent with the ones by Tumbrink who did not observe measurable emissions during refueling (9). Ren and Hao in China did find measurable emissions throughout refueling, but at low levels, with vapor concentration increasing over time and ranging from 0 to 4.5 mg/m^3 (13). Emissions could be the result of a leak in part of the vehicle's fuel system, aging of the activation sites or oversaturation of the charcoal filter used in the ORVR, or a malfunctioning mechanical seal. It is also possible that that the pump nozzle itself is damaged, resulting in vapor release. In addition, Ren and Hao found that ambient temperature, fuel temperature, filling flow, and filling pipe diameter all have an impact on the time to liquid seal formation and on vapor emissions (13). Emissions were increased when either ambient or fuel temperature was higher (13). As our study was conducted at cold ambient temperatures (0.5–5°C), we expect that emissions during Spring, Summer, and Fall would be greater than what we observed.

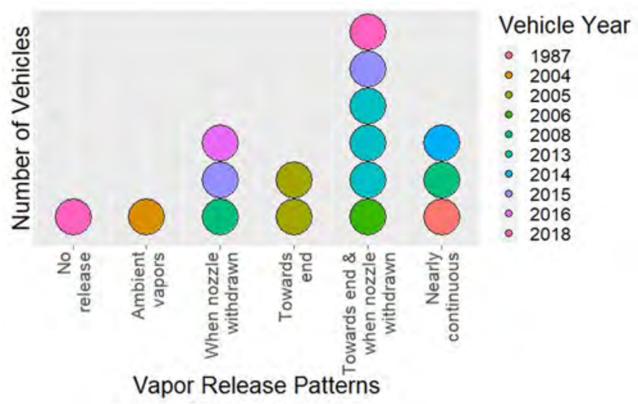

FIGURE 1 | Dotplot depicting the number of vehicles in each vapor release category (each dot represents one vehicle), with year delineated by color.

Our study found an average refueling time of 86 s (1.43 min), similar to the 1.13 min found by Vainiotalo et al. (5) in Finland and less than that found by Egeghy et al. (7) in North Carolina (median of 3 min). These studies, and others, included various biomarkers and measures of exposure: internal dose (blood) (6), exhaled breath (7), and breathing zone air (5–7), all of which suggested individuals were exposed to benzene, a known human carcinogen, during refueling. As all studies were conducted before widespread adoption of ORVR and only at gas stations without Stage II vapor recovery, their results are likely not representative of the typical exposure today. Somewhat concerningly, however, our study suggests that despite extensive use of ORVR, individual exposures at similar magnitudes to those experienced before ORVR requirements were implemented may still occur—two of the three refueling

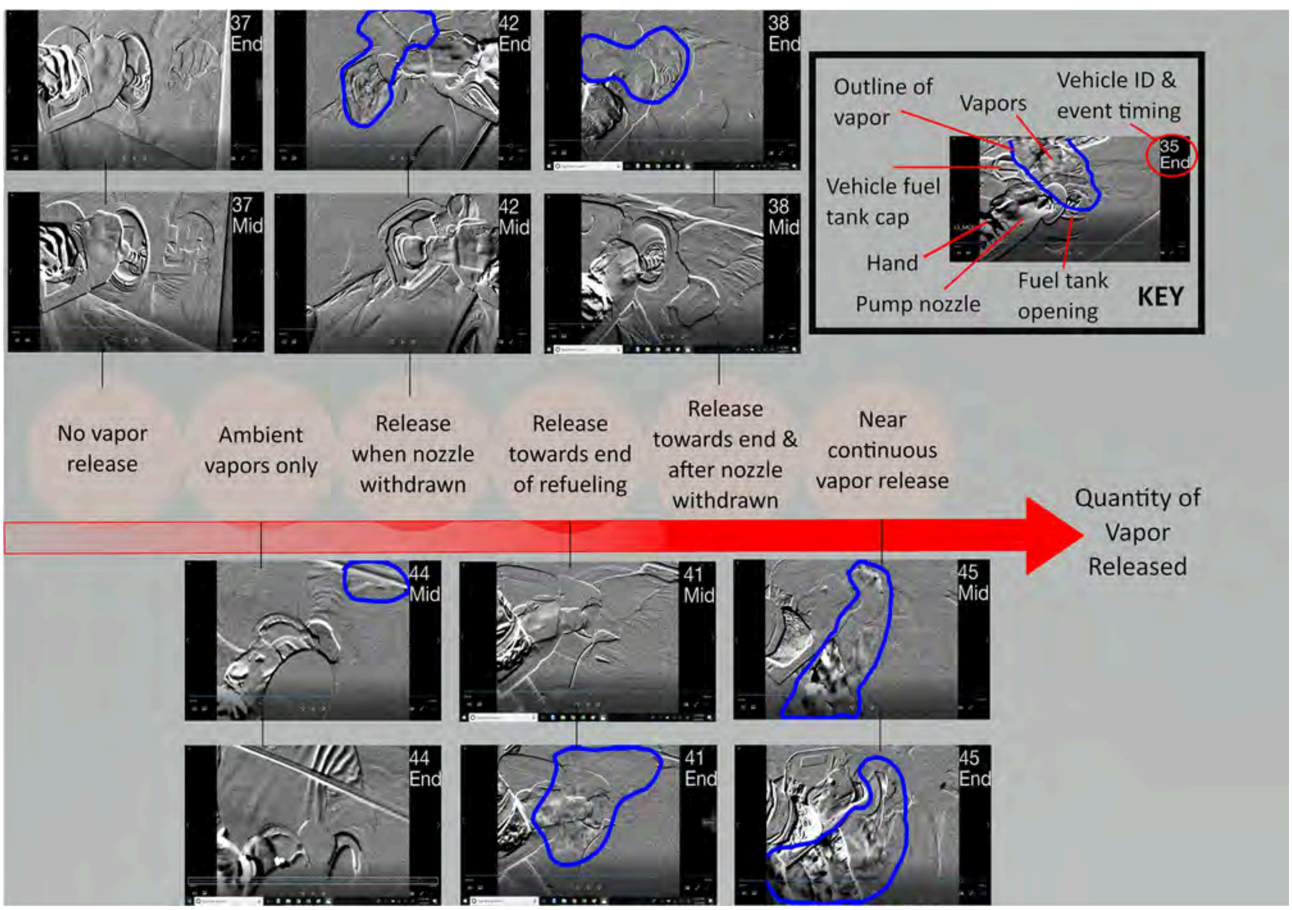

FIGURE 2 | Two sample frames for each of the 6 identified patterns of vapor release during refueling: one during the middle of the refueling session, and one at the end. Vehicle ID and an indicator for middle ("Mid") or end ("End") of the video are included in the upper right corner of each photo. Gasoline vapors, when present, are outlined by a blue line.

events categorized as "near continuous vapor release" happened in vehicles manufactured after the rollout of ORVR. Without Stage II vapor recovery, the population is not protected from emissions arising from the so-called legacy fleet without ORVR, vehicles with deteriorating ORVR, or motorcycles and boats, both of which do not have ORVR.

Of particular importance for public health and policy is the ability of ORVR systems to (1) reduce exposure to gasoline vapors during refueling to a safe level, and (2) continue to function at a high level over the lifetime of a vehicle. This is important for two reasons. First, volatile organic compounds (VOCs) released during refueling can chemically react in the atmosphere, contributing to ozone and other secondary pollutant formation, which can harm human health directly through cardiovascular pathways (14). ORVR systems are intended to reduce this potential, by preventing VOCs from escaping into the atmosphere where they can react with other species. Second, as previously discussed, exposure to primary VOCs, such as those in gasoline can also negatively impact health directly, from exposure during vehicle refueling. However, limited work has been conducted to test the assumption that ORVR reduces exposure to a "safe" level during vehicle refueling. In fact, it is unclear what a "safe" level of exposure to gasoline vapors is, particularly as there is not a standardized formula for gasoline.

Numerous studies have been conducted (15, 16) to characterize the potential harms of gasoline with specific formulas or additives, but these reports typically compare different formulas of gasoline rather than comparing exposure to no exposure. Evidence suggests that while exposure during refueling is likely, health effects from gasoline at infrequent low-levels may be small, although individual components are carcinogenic (15, 16). Conversely, evidence from occupational studies has shown that individuals chronically exposed to lower levels of gasoline vapors, for example gas station attendants, are at higher risk for certain cancers (17, 18). Despite this evidence, we do not fully understand what risk gasoline vapors pose to the general public during typical vehicle refueling, or the cumulative impact of such exposure over an individual's lifetime, particularly in today's regulatory environment. Our findings highlight, in a visually compelling manner, that individuals can be exposed to substantial amounts of gasoline vapors during refueling, even in a vehicle fleet saturated with ORVR.

Future studies are vitally needed to determine the risk to individuals during typical refueling sessions in a vehicle fleet saturated with ORVR, especially because exposure to gasoline is ubiquitous and occurs throughout the lifetime. We recommend comprehensive exposure assessments that estimate exposure, internal dose, and health effects, as well as real-time monitoring of volatile organic compounds, potentially using a portable SHED (19) deployed at a gas station and paired with an infrared camera optimized for gas imaging. In addition, we recommend future work to develop an algorithm for estimating the amount or concentration of vapors shown in video from an infrared camera, to provide a better understanding of the concentration of vapors dispersing around a station.

This pilot study has several limitations. First, a convenience sample of stations and vehicles were used, and thus may not be representative of the true vehicle fleet in NYC. However, ORVR saturation in our sample was fairly close to an estimate for all registered vehicles in New York State and City (94 vs. 81%). It is additionally reassuring that both these estimates are above the EPA estimate of 71% for ORVR saturation in the older 2012 US fleet (8) and that the saturation in our convenience sample is above New York State's modeled estimate of 85% or greater for the older 2013 fleet (20). The median manufacturing year of our sample was consistent with that for New York State and City's registered vehicles (median = 2013). Second, the small sample size does not provide ample power for statistical tests. Third, vehicle make, model, and age were estimated by researchers and therefore there is potential for misclassification. Finally, real-time estimates of VOC concentrations were not obtained.

CONCLUSIONS

In an ORVR saturated vehicle fleet, use of an infrared camera optimized for VOC imaging allowed for the identification of vapor sources, viewing vapor trajectory and dispersion, and identifying the timing of vapor release during refueling. In this pilot study, 14 out of 16 observed refueling events resulted in vapor emissions, with severity varying substantially by vehicle make/model and age. A full exposure-assessment incorporating infrared cameras, quantitative monitors, and biologic samples is needed to understand exposure to and health effects of fuel vapor at gas stations, in an ORVR saturated vehicle fleet.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

MH and JS conceptualized the study and completed data collection. JS wrote the first manuscript draft and completed initial data analysis. MH supervised and reviewed all the data analysis and edited the manuscript. All authors agree to be accountable for the content of this work.

FUNDING

MH was supported by NIEHS grant P30 ES009089. JS was supported by NIEHS grant T32 ES007322. The funding sources had no involvement in study design, collection, analysis, and interpretation of data, manuscript development, or publication.

ACKNOWLEDGMENTS

The authors would like to thank Mark Fishburn of FLIR Systems for facilitating the use of the FLIR GF320 infrared camera for a short test period and Sebastian Rowland for his help reviewing the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00018/full#supplementary-material

REFERENCES

1. Hilpert M, Mora BA, Ni J, Rule AM, Nachman KE. Hydrocarbon release during fuel storage and transfer at gas stations: environmental and health effects. *J Curr Environ Health Rep.* (2015) 2:412–22. doi: 10.1007/s40572-015-0074-8
2. Hilpert M, Rule AM, Adria-Mora B, Tiberi T. Vent pipe emissions from storage tanks at gas stations: implications for setback distances. *Sci Total Environ.* (2019) 650:2239–50. doi: 10.1016/j.scitotenv.2018.09.303
3. ATSDR. *Toxicological Profile for Benzene. Agency for Toxic Substances and Disease Registry*. Atlanta, GA: US Department of Health and Human Services (2007).
4. Abou-ElWafa HS, Albadry AA, El-Gilany AH, Bazeed FB. Some biochemical and hematological parameters among petrol station attendants: a comparative study. *Biomed Res Int*. (2015) 2015:418724. doi: 10.1155/2015/418724
5. Vainiotalo S, Peltonen Y, Ruonakangas A, Pfäffli P. Customer exposure to MTBE, TAME, C6 alkyl methyl ethers, and benzene during gasoline refueling. *Environ Health Perspect.* (1999) 107:133–40. doi: 10.1289/ehp.99107133
6. Backer LC, Egeland GM, Ashley DL, Lawryk NJ, Weisel CP, White MC, et al. Exposure to regular gasoline and ethanol oxyfuel during refueling in Alaska. *Environ Health Perspect.* (1997) 105:850–5. doi: 10.1289/ehp.97105850
7. Egeghy PP, Tornero-Velez R, Rappaport SM. Environmental and biological monitoring of benzene during self-service automobile refueling. *Environ Health Perspect.* (2000) 108:1195–202. doi: 10.1289/ehp.001081195
8. EPA. 40 CFR Part 51: Air Quality: Widespread Use for Onboard Refueling Vapor Recovery and Stage II Waiver. *Environmental Protection Agency. Federal Register*. (2012) 77:28772–82.
9. Tumbrink, M. *Filtersysteme im Automobil: Innovative Lösungsansätze für die Automobilindustrie [Filtration Systems in the Car: Innovative Solution Approaches for Car* Manufacturers]: Haus de Technik–Fachbuchreihe (Tübingen) (2002).
10. Schifter I, Díaz L, Rodríguez R, González-Macías C. The contribution of evaporative emissions from gasoline vehicles to the volatiel organic compound inventory in Mexico City. *Environ Monit Assess.* (2014) 186:3969–83. doi: 10.1007/s10661-014-3672-2
11. R Core Team. *R: A Language and Environment for Statistical Computing.* Vienna: R Foundation for Statistical Computing (2018).
12. Wickham H. *Tidyverse: Easily Install and Load the 'Tidyverse'*. R package version 1.2.1 (2017).
13. He R, Ding H. Refueling experiment of on-board refueling vapor recovery. *China J Highw Transp.* (2017) 30:142–50.
14. Zhao R, Chen S, Wang W, Huang J, Wang K, Liu L, et al. The impact of short-term exposure to air pollutants on the onset of out-of-hospital cardiac arrest: a systematic review and meta-analysis. *Int J Cardiol.* (2017) 226:110–7. doi: 10.1016/j.ijcard.2016.10.053
15. ATSDR. *Toxicological Profile for Gasoline*. Agency for Toxic Substances and Disease Registry. Atlanta, GA: US Department of Health and Human Services (1995).
16. NSCAUMATC. *Evaluation of the Health Effects From Exposure to Gasoline and Gasoline Vapors*. Northeast States for Coordinated Air Use Management Air Toxics Committee (1989).
17. Morton W, Marjanovic D. Leukemia incidence by occupation in the Portland-Vancouver metropolitan area. *Am J Ind Med.* (1984) 6:185–205. doi: 10.1002/ajim.4700060304
18. Schwartz E. Proportionate mortality ratio analysis of automobile mechanics and gasoline service station workers in New Hampshire. *Am J Ind Med.* (1987) 12:91–9. doi: 10.1002/ajim.4700120110
19. Eastern Research Group. *Denver Summer 2008 Pilot Study at Lipan Street Station–Report Version 5*. Assessment and Standards Division, Office of Transportation and Air Quality and United States Environmental Protection Agency (2008).
20. NYDEC. *Stage II Vapor Collection System Enforcement Discretion Directive*. New York, NY: State Department of Environmental Conservation (2011). Available online at: https://www.dec.ny.gov/regulations/74990.html (accessed November 30, 2019).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Monday, May 6, 2024 7:16 PM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

Thank you. Your submission has been received. Submitted on Monday, May 6, 2024 - 7:16pm Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31269 Your Contact Information
First Name William
Last Name Eaton
Phone Number 603-622-6566
Email weaton123061@gmail.com
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
Dear Members of the Planning Board,
I am writing to follow up on the recent planning board meeting where the proposed gas station on Central Street was discussed. During the meeting, I voiced my concerns regarding two specific waivers that were being considered.
Firstly, the waiver to waive the minimum residential requirement is deeply concerning to me, as it appears to prioritize commercial interests over the well-being of residential abutters. I firmly believe that any development in our community should be in harmony with the existing residential character and should not infringe upon the rights and quality of life of nearby residents.
Secondly, the waiver for a second driveway poses significant concerns regarding increased traffic flow and safety in the surrounding neighborhoods. Adding another access point for vehicles could exacerbate existing traffic issues and potentially pose risks to pedestrians and residents alike. It is crucial that any development project takes into account the impact it will have on the surrounding infrastructure and residential areas.
I respectfully request that this letter be made a part of the official record for the proposed gas station project. It is important that the planning board consider all perspectives and concerns raised by members of the community when making decisions that will shape the future of our town.
Thank you for your attention to this matter. I trust that the planning board will carefully weigh the implications of granting these waivers and act in the best interests of the community.
Sincerely,
William Eaton
15 Adelaide St
Hudson NH 03051

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Wednesday, May 8, 2024 4:07 PM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Wednesday, May 8, 2024 - 4:07pm Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31291 Your Contact Information
First Name Colleen
Last Name Baker
Phone Number
Email colleenb3@comcast.net
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
Completely against the gas station proposal at Central/Lowell.
-too many gas stations already
-don’t need additional traffic congestion
-too close to houses/neighborhoods

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Wednesday, May 8, 2024 8:32 AM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Wednesday, May 8, 2024 - 8:32am Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31279 Your Contact Information
First Name Anthony
Last Name Michaud
Phone Number
Email tmichaud@gmail.com
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
I understand there is a proposal for a new gas station by the fireman’s memorial. I would like to voice my opinion that I think this is a terrible idea. I don’t think it fits the nature of the neighborhood, would create more traffic congestion, and comes at a poor time when more vehicles are going electric in the future.
Respectfully,
Anthony Michaud

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Wednesday, May 8, 2024 7:33 AM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Wednesday, May 8, 2024 - 7:32am Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31277 Your Contact Information
First Name Robert
Last Name Everett
Phone Number +16032297319
Email rje7@hotmail.com
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
Regarding Gas station waivers at Lowell and Central please include in public record. My jobs do not allow me to attend meeting as they conflict with times. As for second driveway I really don't care because I always thought that was a dumb rule but at that intersection I believe it would create safety hazards no matter how many signs are put up look at Walgreens, friars court, Irving, accross from fox hollow etc. As for the waiver for the residential most of the buildings accross the street from that are residential and I agree that waiver should be denied. Yes there are a couple commercial buildings near it but it's what I would consider residential especially since the developer tore down residential buildings to begin with.
Sincerely
Rob Everett
220-40 Derry Rd
Hudson

Attachment "F"

Dubowik, Brooke

From: Hudson New Hampshire <hudson-nh@municodeweb.com>
Sent: Friday, May 24, 2024 9:43 AM
To: Dubowik, Brooke
Subject: Form submission from: Contact a Board or Committee

EXTERNAL: Do not open attachments or click links unless you recognize and trust the sender.

Thank you. Your submission has been received. Submitted on Friday, May 24, 2024 - 9:43am Form: Contact a Board or Committee Form ID: 42624 Submission ID: 31394 Your Contact Information
First Name Vicki
Last Name Moore
Phone Number 6037854767
Email vmoore300@msn.con
Select the Board or Committee you would like to contact Planning Board
Question/Comments you'd like to share
I vehemently oppose waivers for a new gas station as do most of my neighbors. Start master planning and stop allowing our town to be turned into a dump. What are the goals of the planning board??? Please register include my comments to the record of the next meeting.