Evaluating Internally Cured High-Performance Concrete Life Cycle Cost Savings in New Jersey Bridges

Presenter: Kaan Ozbay, PhD, Director of C2SMART

NYU Team:

Eren Kaval, PhD Candidate

Jingqin Gao, PhD

RIME Group:

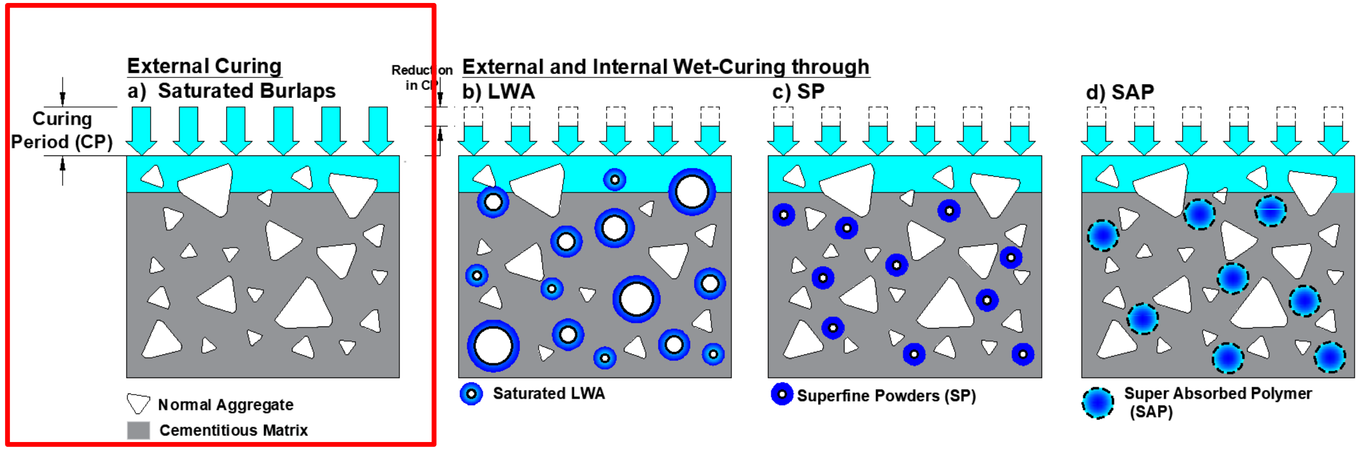
Principal Investigator (PI): Hani **Nassif**, PE, PhD

Micheal Ruszala

Chaekuk Na, PhD

Background

- **Problem:** External curing limits on bridge decks
- Large deck areas → moisture delivery is nonuniform and short lived.
- **Result:** Early shrinkage/cracking, weaker near-surface, poorer abrasion resistance.
- Durability drives life-cycle outcomes (permeability, cracking, rehab timing).



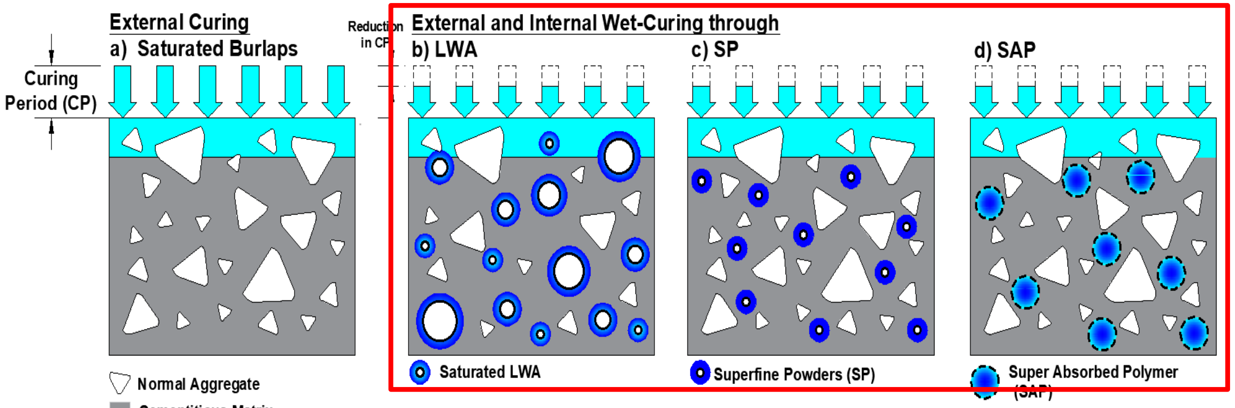
Schematic Description of Curing Process; (a) External Curing (burlap or any equivalent method), External Curing Combined with Internal Curing (b) LWA, (c) SP, and (d) SAP

Extend Service Life of Concrete Bridge Decks with Internal Curing

C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

What is internal curing?

- Add prewetted lightweight fines or superabsorbent polymer that release water internally during hydration.
- Sustains internal humidity → less self-shrinkage and lower permeability.
- Mechanism fits deck reality when external curing is imperfect.
- Delays first crack; extends service life.



Schematic Description of Curing Process; (a) External Curing (burlap or any equivalent method), External Curing Combined with Internal Curing (b) LWA, (c) SP, and (d) SAP

Covered bridge deck during curing.

Importance of Internal Curing

- Later first crack → later first rehab → fewer total interventions over service life.
- Fewer and later interventions → fewer work zones → lower user/social costs.
- Mechanism aligns with DOT experience: reduced cracking in IC-HPC deployments.
- Use HPIC vs HPC in LCCA to capture service-life and rehab-frequency effects.

Crack in 2 months

Crack in 1 year

Project Objectives

- Identification of a cost-effective practice of ICC for bridge deck and concrete pavement applications for NJDOT.
- Reviewing other neighboring states' DOT's specifications, lessons learned, and challenges of the current practices for IC-HPC in the US in Phase I
- Conducting a laboratory testing program tailored to evaluate the use of LWA to produce more durable concrete
- Assessing the technical feasibility of implementation of IC-HPC
- **Performing Life Cycle Cost Analysis (LCCA) for the benefits expected. This research is devoted to promoting the application and production of IC-HPC in NJ**

Life-Cycle Cost Analysis (LCCA)

- **LCCA** is an engineering economic analysis tool used to evaluate the total economic impact of different design, material, or maintenance options over the bridge's entire service life.

Why it is important?

- Considers all agency expenditures and user costs throughout the life of an alternative, not only initial investments
- Offers sophisticated methods to determine the economic merits of the selected alternative
- Critical in evaluating **new construction materials/techniques** to quantify durability benefits and account for inherent uncertainty.

Research Overview

In the context of IC-HPC (or HPIC), where enhanced durability aims to reduce shrinkage, cracking, and permeability, LCCA serves as a critical tool to help understand performance benefits into long-term economic value.

The following analysis was conducted to compare **HPIC vs HPC**:

- **Deterministic LCCA** for quick assessment
- **Probabilistic LCCA** to consider uncertainties such as service life, discount rate, and unit prices
- **CO2 Emission Analysis**: Social Cost of Carbon

Project Level LCCA Model

$$\text{NPV} = \sum_{t=0}^{T} \frac{w_1(AC_t(a_t) - \text{SV}_t) + w_2(TDC_t(a_t, V_t) + VOC_t(a_t, V_t) + CRC_{(t)}(a_t, V_t)) + w_3 \cdot SC_t(a_t, V_t)}{(1+r)^t}$$

- Sums **agency**, **user** and **social** costs over years $t = 0, \ldots, T$,
- Uses a scheduled **M&R action** $a_t$each year costs at year $t$depend on a_t.
- Enforces **feasibility** via deterioration/serviceability: if condition falls below a threshold, next-year rehab/replacement is required. **Salvage** at $t = T$.
- Aggregates components with **weights** $w_1, w_2, w_3$to form total NPV.

Key Variables

- t: year when a cost occurs; 0…T where T: analysis period
- r: Discount rate
- a_t: M&R activity at year t (bound by deterioration function f(CR_t),where CR_t: condition at year t
- V_t: AADT at year t (vehicles/day), includes truck share and growth
- Cost functions per year t display direct and indirect costs

C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

Deterministic LCCA: Spreadsheet-Based Tool

RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group · NJIT New Jersey Institute of Technology · NYU · NORTHEAST SOLITE CORPORATION

- A **spreadsheet-based tool** previously developed by the NYU/RIME research team to integrate life-cycle costs into agency investment decisions is used: Utilized for multiple studies for NJDOT, Missouri DOT, and RECAST UTC projects in the past
- Estimates **deterministic life-cycle costs** for alternative materials by accounting for costs.
- **Design and cost variables** such as FWHA recommended service life, supplier material costs
- **Traffic and Work-zone variables** such as ADT, Truck%
- Analysis conducted for **multiple bridges with various sizes**

Project Detail			
Project site:	Interstate-80		
Construction type (Pavement/bridge):	Bridge Deck		
State:	New Jersey		
Milepost from:	61.1901306	To	61.3100552
Structure Length (feet):	231.9	35898.12	
Structure Width (feet):	154.8		
Structure Thickness Assumption (inch)	8		
Comments:	Bridge built in 1963		

Analysis Option				
Alternatives:	Alternative A:	HPC		
	Alternative B:	HPIC		
Analysis period (years):	75			
Discount rate (%):	2.3%			
Service Life (years):	Alternative A:	25	Alternative B:	40
Material Unit Price ($/cubic yard):	Alternative A:	1500	Alternative B:	1650

Spreadsheet Sample Input Interface

Deterministic LCCA: Inputs & Assumptions

- **Cost and service life inputs** include numerous values ranging from NJDOT compliant parameters (for the accommodation of NJ conditions) to FWHA estimates

Unit Cost Inputs Used:

HPC: $1500/CY, based on NJDOT bid prices

HPIC: A set of costs were used:

- $1650/CY: 10% increase in price based on supplier cost information
- $1800/CY: Reflecting to a 20% increase in price vs HPC per FHWA report*
- $2000/CY: Based on the current higher-end bid prices provided by NJDOT

Note: The analysis incorporates multiple HPIC unit cost assumptions to account for the current higher-end bid prices (~30% increase, as of Nov 2025) which is likely elevated due to limited market experience and the anticipated potential future costs (10%-20% increase) once the material becomes institutionalized and pricing stabilizes.

Service Life Inputs Used:

HPC: 25 years

HPIC: Two service life values were used:

- 40 years: Provided by NJDOT
- 50 years: Based on minimum improvement threshold per FHWA report

*"…can increase the service life of concrete bridge decks by **25 to 50 years**."*

-Internally Curing Concrete Produces EPIC2 Results, FHWA

C2SMART · URBAN MITS Lab @ NYU · RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group · NJIT New Jersey Institute of Technology · NYU · NORTHEAST SOLITE CORPORATION

Deterministic LCCA: Inputs & Assumptions

- Discount Rate:
  - Set at 2.3% based on OMB rate
- 75-year analysis period
- Traffic data from NBIS database:
  - Structure length, width
  - ADT, Truck%, Annual Growth Rate, Lanes
- Maintenance schedules based on NJDOT feedback:
  - HPC: Every 5 years
  - HPIC: Every 10 years
- Initial cost premium has been added to HPIC cost calculations

Sample Bridges from NJ Bridge Database

C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

Deterministic LCCA: Results

Deterministic LCCA on multiple bridges yielded the following cost savings:

Agency Cost:

- HPIC yields agency cost benefits ranging from **15.27% to 40.90%,** depending on unit cost and service life estimates.
- If unit prices stabilize, HPIC can achieve approximately **30–45%** in agency cost savings under NJ conditions (e.g., high salt usage).

Total Cost:

- Similarly, HPIC displays total cost benefits ranging from **15.82% to 44.24%**.

Conclusion: HPIC demonstrates **lower** network present values for all costs compared against HPC.

Note: *The total cost include direct cost (agency cost) and indirect costs (e.g., vehicle delay cost, crash risk cost).*

Agency Cost Benefit Range for a Sample Bridge on I-80

Agency Cost Benefits		HPIC Unit Cost Input ($/CY)		
		Low	Medium	High
		1650	1800	2000
HPIC Service Life	40 yrs	30.67%	24.39%	16.01%
	50 yrs	40.82%	35.46%	28.31%

Total Cost Benefit Range for a Sample Bridge on I-80

Total Cost Benefits		HPIC Unit Cost Input ($/CY)		
		Low	Medium	High
		1650	1800	2000
HPIC Service Life	40 yrs	36.07%	31.48%	25.35%
	50 yrs	44.24%	40.32%	35.09%

Probabilistic LCCA: Inputs and Assumptions

To account for the uncertainty associated with the new material HPIC, a probabilistic LCCA was also performed. The uncertainty was evaluated using Monte Carlo simulations, which involve repeated random draws from specified distributions of input variables.

Cost Input Ranges Used:

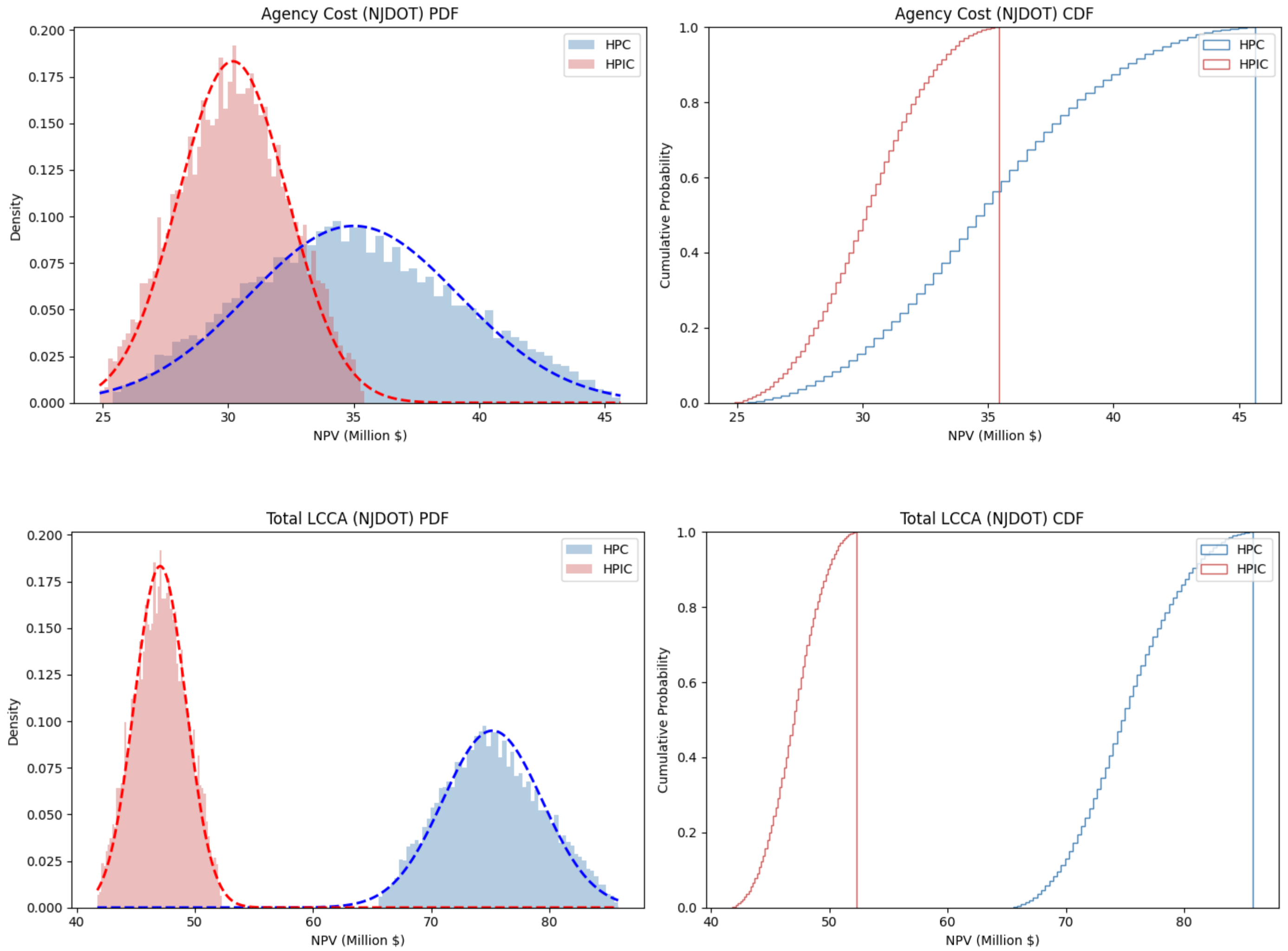
- **Probabilistic Input:** range for both alternatives via triangular distributions ($/CY)
  - **HPC: [min=1100, mode=1500, max=2000]**
  - Based on bidding prices on the Estimation Support and Historical Statistics Report
  - **HPIC: [min=1400, mode=1700, max=2000]**
  - Based on most recent bidding prices provided by NJDOT (November 2025)
- Remaining inputs are kept the same as the deterministic analysis.
- The maintenance schedules have also been updated based on the NJDOT feedback.
- Two service life estimates (40-50 years) for HPIC were used.

Probabilistic LCCA: HPC vs HPIC

Monte Carlo Simulations (10,000 runs) were conducted to create cost distributions from defined input variables.

When HPIC **service life** is set to be **40 years**:

- **Probability (HPIC <u>Agency Cost</u> < HPC Agency Cost)**: **83.8%** and;
- **Probability (HPIC <u>Total Cost</u> < HPC Total Cost): 100%** for all simulated scenarios.



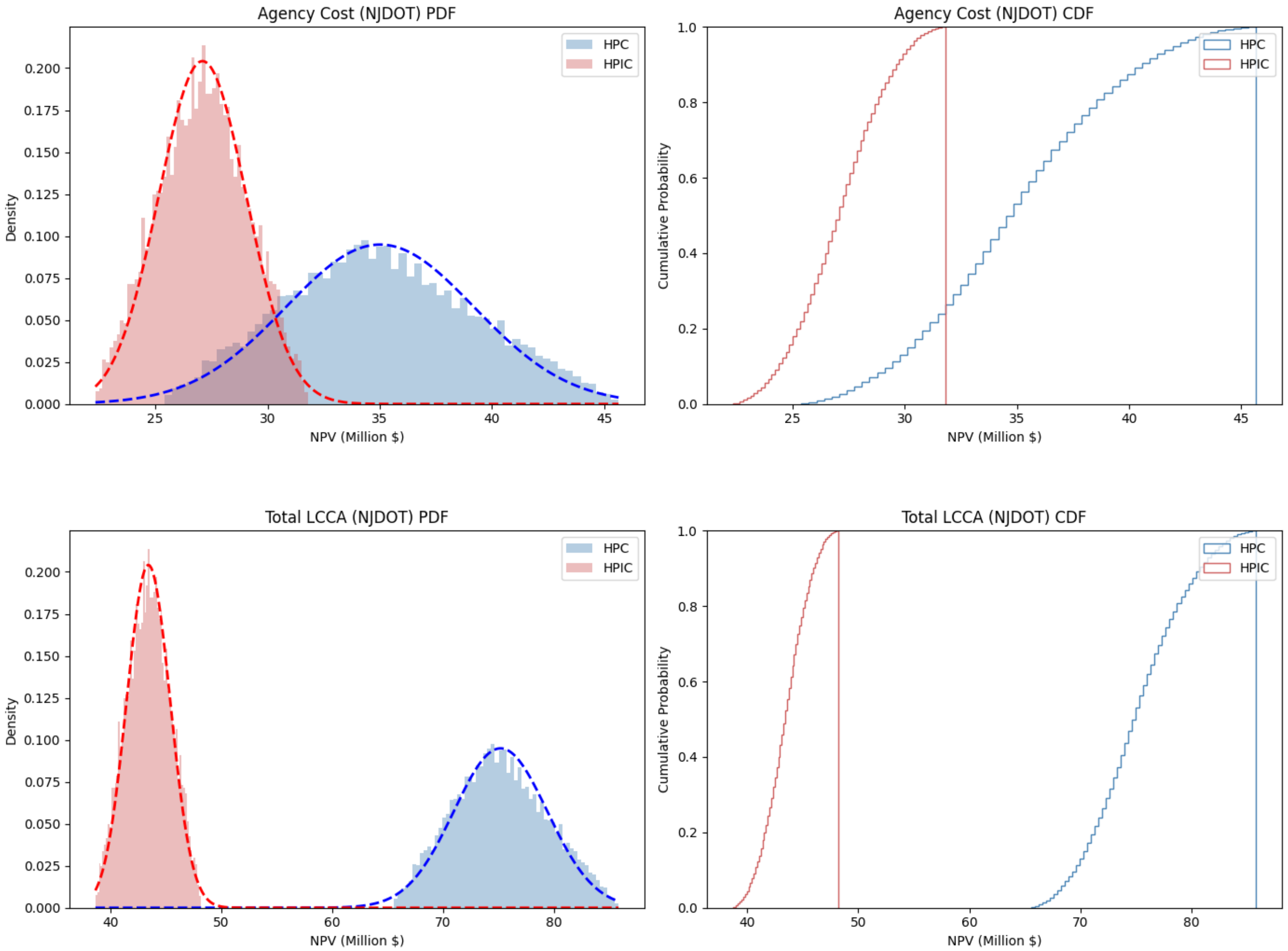
C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

Probabilistic LCCA: HPC vs HPIC

When HPIC **service life** is set to be **50 years** (Based on minimum improvement threshold per FHWA report*):

- **Probability (HPIC Agency Cost < HPC Agency Cost): 95.9%** and;
- **Probability (HPIC Total Cost < HPC Total Cost): 100%** for all simulated scenarios.

Conclusion: With the addition of uncertainty and probabilistic assumptions, **HPIC outperforms HPC** in most cases for both service life assumptions.

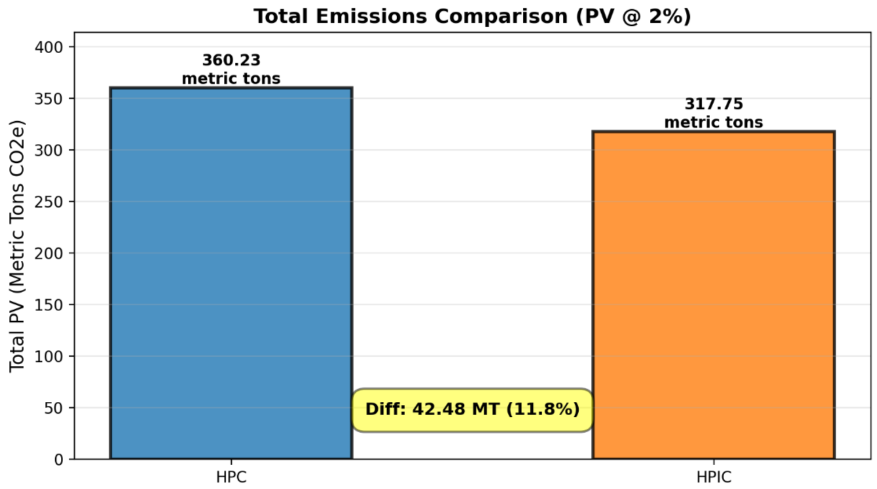


C2SMART · URBAN MITS Lab @ NYU · RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group · NJIT New Jersey Institute of Technology · NYU · NORTHEAST SOLITE CORPORATION

CO2 emission Analysis: Social Cost of Carbon

- The social cost of HPIC was also investigated: **Embodied carbon (lbCO2e/CY):**
- HPIC has a **slightly higher** social cost premium.
- Social Cost of Carbon (SCC) was assumed to be:
  - Mean: $185.00/metric ton CO2
  - 5%-95% Range: $44.00-$413.00/metric ton CO2
- **Conclusion:** Despite the initial extra embodied carbon compared to HPC, **HPIC has a lower SCC value converted to NPV.**
  - **11.8% benefits** with 2% discount rate
  - **7.3% benefits** with 3% discount rate

Discount Rate:	2%	3%
HPC Emissions (metric tons CO2e):	360.23	320.45
HPIC Emissions (metric tons CO2e):	317.75	297.16
Difference (metric tons CO2e):	42.48	23.29
HPC Social Cost (Mean):	$65,757	$59,621
HPIC Social Cost (Mean):	$58,003	$55,287
Percentage Difference:	**11.8%**	**7.3%**



C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

Conclusion

Unit cost, service life, additional HPIC construction costs and maintenance schedule inputs for the deterministic and probabilistic LCCA models reflecting a range of NJDOT compliant conditions to FHWA estimates demonstrate the following results:

- **Deterministic LCCA:** HPIC shows **agency cost savings of 15.27–40.90%** and **total cost savings of 15.82-44.24%** compared to HPC, depending on unit cost assumptions, extended service life and reduced maintenance frequency. If **unit prices stabilize**, HPIC can achieve approximately **30–45%** in agency cost savings under NJ conditions (e.g., high salt usage).
- **Probabilistic LCCA results:** Monte Carlo simulations confirm HPIC's robustness to cost uncertainty:
  - **Agency Cost: 83.8%-95.9%** probability that HPIC's agency cost is lower than HPC's**.**
  - **Total Cost:** HPIC's total cost is always lower across all simulations.

Social cost & CO_2: Despite slightly higher embodied CO_2 per CY, HPIC's longer service life lowers cumulative CO_2; SCC NPV is lower at various discount rates **(~11.8%, ~7.3%).**

Overall: Deterministic and probabilistic evidence together show **HPIC consistently outperforms HPC** in terms of life-cycle cost.

C2SMART URBAN MITS Lab@NYU RUTGERS Infrastructure Monitoring and Evaluation (RIME) Group NJIT New Jersey Institute of Technology NYU NORTHEAST SOLITE CORPORATION

Future Work

- **Price convergence:** Model HPIC unit cost over time using an experience curve or an exponential approach to the HPC price and test scenarios based on this adoption.
- **SCC uncertainty:** Treat SCC as a distribution and propagate through the emissions inventory.
- **Uncertainty types:** Separate parameter uncertainty (prices, SCC, discount rate) from natural variability (traffic, work zone durations) with a two stage Monte Carlo; report both effects.
- **Discount rate:** Use literature-based priors estimated from guidance and past LCCA; use these in Monte Carlo.
- **Applicability:** Expand the bridge sample across sizes, ADT levels, and regions; verify results under varied traffic and logistics conditions.

References

- K. Ozbay, D. Jawad, N.A. Parker, and S. Hussain. "Life-cycle cost analysis: State of the practice versus state of the art." Transportation Research Record, 2004, 1864 (1), pp. 62-70.
- C. Rao and M. Darter. Evaluation of Internally Cured Concrete for Paving Applications, 2013.
- J. Gao, k. Ozbay, H. Nassif, and O. Kalan. “Stochastic Multi-Objective Optimization-Based Life Cycle Cost Analysis for New Construction Materials and Technologies.” Transportation Research Record, 2019, 2673(11), pp. 466-479.
- H. Nassif, A. Abu-Obeidah, C. Na, K. Ozbay, J. Gao and K.H. Khayat. “Flexural Performance of Concrete Beams Strengthened using Different Repair Techniques.” Research on Concrete Applications for Sustainable Transportation (RE-CAST UTC). 2019.
- NJDOT, Cost Estimating Guideline, 2019.
- Rennert, K., Errickson, F., Prest, B.C. et al. Comprehensive evidence implies a higher social cost of CO2. Nature 610, 687–692 (2022). https://doi.org/10.1038/s41586-022-05224-9
- Holcim, Whitehall Cement Plant Environmental Product Declaration. https://pcr-epd.s3.us-east-2.amazonaws.com/606.EPD_FOR_Lafarge_Whitehall.pdf
- Holcim, Sparrows Point MD Slag cement plant Environmental Product Declaration. https://pcr-epd.s3.us-east-2.amazonaws.com/762.Holcim+Slag+EPD+Sparrows+Point+-+Final%2C+March+31%2C+2022.pdf
- Vulcan Materials Company Environmental Product Declaration. https://vulcanmaterials.azureedge.net/content-v2/docs/default-source/default-document-library/pleasanton-epd_final.pdf
- Euclid Canada Inc. Chemical Admixtures for Concrete, An Environmental Product Declaration. https://pcr-epd.s3.us-east-2.amazonaws.com/1188.Euclid_Canada_Chemical_Admixtures_EPD_20240628_FINAL.pdf
- *First Quarter 2023 Estimation Support and Historical Statistics BAMS/DSS® Output, NJDOT. https://dot.nj.gov/transportation/business/aashtoware/pdf/1stQuarter2023.pdf*
- *Internally Curing Concrete Produces EPIC2 Results, FHWA. https://www.fhwa.dot.gov/innovation/innovator/issue98/page_01.html*

Thank you for your attention.
Questions?

Principal Investigator (PI): Hani **Nassif**, PE, PhD

Contact Information:
Kaan Ozbay, PhD, Professor & Director C2SMART Center,
New York University Tandon School of Engineering 6
MetroTech Center, Brooklyn, NY 11201
Email: kaan.ozbay@nyu.edu
C2SMART Website: c2smart.engineering.nyu.edu
Email: c2smart@nyu.edu