

Background: Methane Functionalization The current industrial means of methane (natural gas) utilization can have negative implications from its liquefaction and storage, on top of those from the economic standpoint¹. Solution: methane functionalization While many scientists and researchers have explored transitional metal complexes as catalysts for alkane functionalization^{2,3,4}, the Goldberg group aims to achieve selective alkane functionalization using oxygen as a sustainable, terminal oxidant⁵. **Reaction:** Metal-Free Alkane Iodination **Fast anaerobic regime** hv (390 nm) + 2 I₂ + [Bu₄N]⁺[Cl]⁻ + HCl + $[Bu_4N]^+[I_3]^-$ CH₃CN, O₂ Slow aerobic regime 4 HCl + O_2 + 4 [Bu₄N]⁺[I₃]⁻ $\xrightarrow{hv (390 nm)}$ \rightarrow 6 I₂ + 2 H₂O + 4 [Bu₄N]⁺[Cl]⁻ **Net Reaction** hv (390 nm) $+ 2 I_2 + O_2 \xrightarrow{\text{inv}(330 \text{ min})} 4$ + $2 H_2 O$ Cl⁻ (20 mol %), CH₃CN **Important Notes:** Too much I_2 is inhibits the overall catalytic activity but is necessary as a reagent to selectively produce iodinated alkyl products over oxygenated products (cyclohexanol and cyclohexanone) O_2 serves as the terminal oxidant and the thermodynamic driving force to propel the catalytic cycle Cl⁻ is the photocatalyst which must be regenerated to generate one catalytic turnover (one equivalent of functionalized cyclohexane) **Prior Work:** Water Optimization An optimal condition of 1% water (v/v%) in solvent CH_3CN was determined. **Fig. 1** A schematic of the H₂O-HCl interactions in the slow aerobic regime of the metal-free alkane iodination reaction, is shown.



Investigating Photolytic Aerobic Alkane Iodination Catalysis

Nidhi Ohri, Nate A. Hirscher, Karen I. Goldberg Department of Chemistry, University of Pennsylvania, Philadelphia, PA, 19104

Reaction Scale-Up

Continuous flow photochemistry as a field has grown in its popularity for the key reasons of being able to safely and systematically create target products in a reproducible manner⁷. In this project, the batch reactor design and flow reactor design were explored.



Motivation & Objective:

Improve the overall catalytic activity of the iodination reaction.

Fine-tune the selectivity of the iodinated alkyl product as a function of time and other experimental parameters.

Batch Reactor Design



Flow Reactor Design

Flow-Reactor Experiments Conditions 99% stock (ttbbz/tbaCl/MeCN) 1% water Baseline 240 µL CyH Reference $[CI^{-}] = 1.1 \text{ mM} [I_2] = 31 \text{ mM}$ $[O_2] = 2.6 \text{ mM}$ **Changed Parameters Inlet Stream** Experiment Solution Addition **Notes** Rate [µL/min] 9.33 -18.67 $2 \times rate$ 18.67 Duplication of "B" 46.67 5× rate 2× rate w/ 18.67 cooling



Triphasic Process

Each phase has a variable length & volume

Fig. 3 Productivity of CyH functionalization^{a,b} and selectivity of Cyl production, reported as turnover number (TON) and product yield.

tube covered





Conclusions

- The iodination of cyclohexane can be successfully facilitated with an aerobic, metal-free photochemical process.
- The optimal water condition to maximize total catalytic productivity exists at 1% (v/v %) water in CH_3CN (See Fig. 1)
- A batch reactor design with pumping of I_2 reagent allows for linear catalytic productivity over the course of experiment (See Fig. 2)
- A flow reactor design has large source of error that needs identification but gives faster catalytic productivity (See Fig. 3)

Future Directions

Future work and plans include:

- Modifying more parameters of the flow system to understand its functionality (i.e., temperature monitoring, diffusion of species across system, etc.)
- Exploring iridium photochemistry under green-light to achieve selectivity for roles of species within the proposed reaction mechanism.



Outer-sphere photo-sensitized oxidation of Cl⁻ anions (as shown) via an Ir(IV) aquo complex as a result of photoexcitation could be an alternative to $[I_2CI^-]$ speciation as the means of generating CI[•] radical

References

- . U.S. Energy Information Administration EIA Independent Statistics and Analysis. https://www.eia.gov/energyexplained/natural-gas/ (accessed Apr 25, 2021).
- 2. Munz, D.; Strassner, T. Alkane C–H Functionalization and Oxidation with Molecular Oxygen. pubs.acs.org. DOI: 10.1021/ic502515x
- 3. Waltz, K. M.; Hartwig, J. F. Selective Functionalization of Alkanes by Transition-Metal Boryl Complexes. Science 1997, 277 (5323).
- I. Pérez, Pedro J. "Alkane Carbon-Hydrogen Bond Functionalization with (NHC)MCI Precatalysts (M = Cu, Au; NHC = N-Heterocyclic Carbene)." Organometallics. 25.9 (2006): 2237–2241. Web.
- 5. Goldberg, K. I.; Goldman, A. S. Large-Scale Selective Functionalization of Alkanes. Acc. Chem. Res. 2017, 50 (3), 620–626.
- 5. Kütt, A.; Tshepelevitsh, S.; Saame, J.; Lõkov , M.; Kaljurand, I.; Selberg, S.; Leito, I. Strengths of Acids in Acetonitrile. EurJOC.
- Donnelly, K., & Baumann, M. (2021). Scalability of photochemical reactions in continuous flow mode. Journal of Flow Chemistry. doi:10.1007/s41981-021-00168-z

Acknowledgments

Thank you, Professor Karen I. Goldberg, Dr. Nate A. Hirscher, and the Goldberg Lab Group for their valuable time, resources, and mentorship.