# IMIDAZOPYRIDAZINE COMPOUNDS WITH ACTIVITY AS ALK2 INHIBITORS

## CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims priority to, and the benefit of, Provisional Application No. 63/038,410, filed June 12, 2020 entitled "IMIDAZOPYRIDAZINE COMPOUNDS AND USES THEREOF", the entirety of which is incorporated herein by reference.

## FIELD OF THE INVENTION

The disclosure provides imidazopyridazine compounds as well as their compositions and methods of use. The compounds modulate activin receptor-like kinase-2 (ALK2) activity and are useful in the treatment of various diseases including cancer.

## BACKGROUND OF THE INVENTION

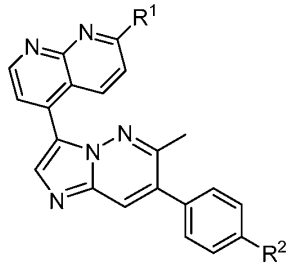
Bone morphogenetic protein (BMP) signaling belongs to the transforming growth factor beta (TGF-β) superfamily and TGF-β signaling ligands include more than 25 different ligands: TGF-β growth and differentiation factors, BMPs and Activins. The binding of BMP ligands leads to the assembly of tetrameric receptor complexes composed of two constitutively-active type II receptor serine/threonine kinases (BMPRII, ACTRIIA, or ACTRIIB) and activate two type I receptor serine/threonine kinases (ALK1, ALK2, ALK3, or ALK6). Furthermore, the activated type I receptors phosphorylate BMP receptor responsive SMAD proteins 1/5/8 and the activated SMAD1/5/8 associated with co-SMAD4 translocate to the nucleus to regulate gene transcription. (Ross, S.L., et al. Cell Metabolism 2012, 15, 905-917; Blobe, G.C., et al. New England Journal of Medicine 2000, 342, 1350-1358).

BMPR kinase activin A receptor, type I (ACVR1) is also called activin receptor-like kinase-2 (ALK2). It is composed of a ligand-binding extracellular domain and a cytoplasmic domain with serine/threonine specificity. ALK2 has been reported to mediate multiple human diseases (Massague, J., et al. Cell 2000, 103, 295-309; Taylor, K.R., et al. Cancer Research 2014, 74, 4565-4570). ALK2 and ALK3 have been shown to play an essential role in regulating the hepcidin levels and affecting the anemia of chronic disease (Andriopoulos, B., et al. Nature Genetics 2009 41, 482-487; Steinbicker, A.U., et al. Blood 2011, 118, 4224-4230; Steinbicker, A.U., et al. Blood 2011, 117, 4915-4923). Hepcidin is a small peptide hormone primarily synthesized in hepatocytes and reduces both duodenal iron absorption and

iron export from monocytes/macrophages by binding to and inducing the internalization and degradation of the iron exporter ferroportin (FPN1) (Theurl, I. et al. Haematologica 2011, 96, 1761-1769; Zhao, N., et al. Journal of Clinical Investigation 2013, 123, 2337-2343). The elevated serum hepcidin levels enhance storage of iron within the reticuloendothelial system and result in reduced iron availability and iron restricted erythropoiesis. Inappropriately increased hepcidin expression causes severe functional iron deficiency anemia in humans and is central to the pathophysiology of anemia of chronic disease (ACD) (Weiss, G. et al. New England Journal of Medicine 2005, 352, 1011-1023). Accordingly, there is a need for new compounds that modulate ALK2 activity.

## SUMMARY

The present disclosure provides, *inter alia*, a compound of Formula I:



I

or a pharmaceutically acceptable salt thereof, wherein constituent variables are defined herein.

The present disclosure further provides a compound selected from: 2-(1-ethyl-1H-imidazol-4-yl)-5 -(6-methyl-7-(4-((1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine; 2-(4-(3-(7-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridin-4-yl)-6-methylimidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane; 2-(4-Methyl-2H-1,2,3-triazol-2-yl)-5-(6-methyl-7-(4-((1S,5R)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine; and 2-(4-(6-methyl-3-(7-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridin-4-yl)imidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane; or a pharmaceutically acceptable salt thereof.

The present disclosure further provides a pharmaceutical composition comprising a compound of the disclosure, or a pharmaceutically acceptable salt thereof, and at least one pharmaceutically acceptable carrier or excipient.

The present disclosure further provides a method of inhibiting ALK2 activity comprising contacting ALK2 with a compound of the disclosure, or a pharmaceutically acceptable salt thereof.

The present disclosure further provides a method of treating cancer in a patient comprising administering to the patient a therapeutically effective amount of a compound of the disclosure, or a pharmaceutically acceptable salt thereof.

The present disclosure further provides a method of treating cancer in a patient, wherein said method comprises administering to the patient a therapeutically effective amount of a compound of the disclosure, or a pharmaceutically acceptable salt thereof, in combination with a further therapeutic agent.

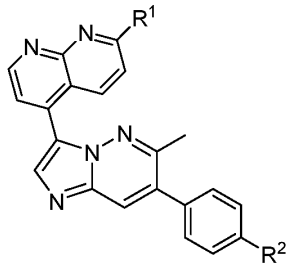
The present disclosure further provides a compound of the disclosure, or a pharmaceutically acceptable salt thereof, for use in therapy.

The present disclosure further provides use of a compound of the disclosure, or a pharmaceutically acceptable salt thereof, for the preparation of a medicament for use in any of the therapeutic methods described herein.

## DETAILED DESCRIPTION

*Compounds*

The present disclosure provides a compound of Formula I:



I

or a pharmaceutically acceptable salt thereof, wherein:

$R^1$ is selected from 1-ethyl-1H-imidazol-4-yl and 4-methyl-2H-1,2,3-triazol-2-yl; and

$R^2$ is selected from (1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl and 2-methyl-2-azabicyclo[2.2.2]octane.

In some embodiments, wherein when $R^1$ is 4-methyl-2H-1,2,3-triazol-2-yl, $R^2$ is not (1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl.

In some embodiments, the compound of Formula (I) is selected from:

2-(1-ethyl-1H-imidazol-4-yl)-5-(6-methyl-7-(4-((1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine;

2-(4-(3-(7-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridin-4-yl)-6-methylimidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane; and

2-(4-(6-methyl-3-(7-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridin-4-yl)imidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane.

In some embodiments, the compound of Formula (I) is selected from:

2-(1-ethyl-1H-imidazol-4-yl)-5-(6-methyl-7-(4-((1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine;

2-(4-(3-(7-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridin-4-yl)-6-methylimidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane;

2-(4-(6-methyl-3-(7-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridin-4-yl)imidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane; and

2-(4-Methyl-2H-1,2,3-triazol-2-yl)-5-(6-methyl-7-(4-((1S,5R)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine.

In some embodiments, the present disclosure provides a compound which is 2-(4-Methyl-2H-1,2,3-triazol-2-yl)-5-(6-methyl-7-(4-((1S,5R)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine, or a pharmaceutically acceptable salt thereof.

It is further appreciated that certain features of the present disclosure, which are, for clarity, described in the context of separate embodiments, can also be provided in combination in a single embodiment (while the embodiments are intended to be combined as if written in multiply dependent form). Conversely, various features of the present disclosure, which are, for brevity, described in the context of a single embodiment, can also be provided separately or in any suitable subcombination. Thus, it is contemplated as features described as embodiments of the compounds of Formula (I) can be combined in any suitable combination.

The compounds described herein can be asymmetric (*e.g.*, having one or more stereocenters). All stereoisomers, such as enantiomers and diastereomers, are intended unless otherwise indicated. Compounds of the present invention that contain asymmetrically substituted carbon atoms can be isolated in optically active or racemic forms. Methods on how to prepare optically active forms from optically inactive starting materials are known in the art, such as by resolution of racemic mixtures or by stereoselective synthesis. Many

geometric isomers of olefins, C=N double bonds and the like can also be present in the compounds described herein, and all such stable isomers are contemplated in the present invention. *Cis* and *trans* geometric isomers of the compounds of the present invention are described and may be isolated as a mixture of isomers or as separated isomeric forms.

Resolution of racemic mixtures of compounds can be carried out by any of numerous methods known in the art. One method includes fractional recrystallization using a chiral resolving acid which is an optically active, salt-forming organic acid. Suitable resolving agents for fractional recrystallization methods are, *e.g.*, optically active acids, such as the D and L forms of tartaric acid, diacetyltartaric acid, dibenzoyltartaric acid, mandelic acid, malic acid, lactic acid or the various optically active camphorsulfonic acids such as β-camphorsulfonic acid. Other resolving agents suitable for fractional crystallization methods include stereoisomerically pure forms of α-methylbenzylamine (*e.g.*, *S* and *R* forms, or diastereomerically pure forms), 2-phenylglycinol, norephedrine, ephedrine, *N*-methylephedrine, cyclohexylethylamine, 1,2-diaminocyclohexane and the like.

Resolution of racemic mixtures can also be carried out by elution on a column packed with an optically active resolving agent (*e.g.*, dinitrobenzoylphenylglycine). Suitable elution solvent composition can be determined by one skilled in the art.

In some embodiments, the compounds of the present disclosure have the (*R*)-configuration. In other embodiments, the compounds have the (*S*)-configuration. In compounds with more than one chiral centers, each of the chiral centers in the compound may be independently (*R*) or (*S*), unless otherwise indicated. Compounds with two chiral centers can, for example, have (*R*,*R*), (*R*,*S*), (*S*,*R*) or (*S*,*S*) configurations.

Compounds of the present disclosure also include tautomeric forms. Tautomeric forms result from the swapping of a single bond with an adjacent double bond together with the concomitant migration of a proton. Tautomeric forms include prototropic tautomers which are isomeric protonation states having the same empirical formula and total charge. Example prototropic tautomers include ketone – enol pairs, amide - imidic acid pairs, lactam – lactim pairs, enamine – imine pairs, and annular forms where a proton can occupy two or more positions of a heterocyclic system, *e.g.*, 1*H*- and 3*H*-imidazole, 1*H*-, 2*H*- and 4*H*- 1,2,4-triazole, 1*H*- and 2*H*- isoindole and 1*H*- and 2*H*-pyrazole. Tautomeric forms can be in equilibrium or sterically locked into one form by appropriate substitution.

Compounds of the present disclosure can also include all isotopes of atoms occurring in the intermediates or final compounds. Isotopes include those atoms having the same

atomic number but different mass numbers. For example, isotopes of hydrogen include tritium and deuterium. One or more constituent atoms of the compounds of the present disclosure can be replaced or substituted with isotopes of the atoms in natural or non-natural abundance. In some embodiments, the compound includes at least one deuterium atom. For example, one or more hydrogen atoms in a compound of the present disclosure can be replaced or substituted by deuterium. In some embodiments, the compound includes two or more deuterium atoms. In some embodiments, the compound includes 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 or 12 deuterium atoms. Synthetic methods for including isotopes into organic compounds are known in the art (Deuterium Labeling in Organic Chemistry by Alan F. Thomas (New York, N.Y., Appleton-Century-Crofts, 1971; The Renaissance of H/D Exchange by Jens Atzrodt, Volker Derdau, Thorsten Fey and Jochen Zimmermann, Angew. Chem. Int. Ed. 2007, 7744-7765). Isotopically labeled compounds can used in various studies such as NMR spectroscopy, metabolism experiments, and/or assays.

Substitution with heavier isotopes such as deuterium, may afford certain therapeutic advantages resulting from greater metabolic stability, for example, increased in vivo half-life or reduced dosage requirements, and hence may be preferred in some circumstances. (A. Kerekes et.al. *J. Med. Chem.* **2011**, *54*, 201-210; R. Xu et.al. *J. Label Compd. Radiopharm.* **2015**, *58*, 308-312).

The term, "compound," as used herein is meant to include all stereoisomers, geometric isomers, tautomers and isotopes of the structures depicted. The term is also meant to refer to compounds of the present disclosure, regardless of how they are prepared, e.g., synthetically, through biological process (e.g., metabolism or enzyme conversion), or a combination thereof.

All compounds, and pharmaceutically acceptable salts thereof, can be found together with other substances such as water and solvents (*e.g.*, hydrates and solvates) or can be isolated. When in the solid state, the compounds described herein and salts thereof may occur in various forms and may, *e.g.*, take the form of solvates, including hydrates. The compounds may be in any solid state form, such as a polymorph or solvate, so unless clearly indicated otherwise, reference in the specification to compounds and salts thereof should be understood as encompassing any solid state form of the compound.

In some embodiments, the compounds of the present disclosure, or salts thereof, are substantially isolated. By "substantially isolated" is meant that the compound is at least partially or substantially separated from the environment in which it was formed or detected. Partial separation can include, *e.g.*, a composition enriched in the compounds of the present

disclosure. Substantial separation can include compositions containing at least about 50%, at least about 60%, at least about 70%, at least about 80%, at least about 90%, at least about 95%, at least about 97%, or at least about 99% by weight of the compounds of the present disclosure, or salt thereof.

The phrase "pharmaceutically acceptable" is employed herein to refer to those compounds, materials, compositions and/or dosage forms which are, within the scope of sound medical judgment, suitable for use in contact with the tissues of human beings and animals without excessive toxicity, irritation, allergic response, or other problem or complication, commensurate with a reasonable benefit/risk ratio.

The expressions, "ambient temperature" and "room temperature," as used herein, are understood in the art, and refer generally to a temperature, *e.g.*, a reaction temperature, that is about the temperature of the room in which the reaction is carried out, *e.g.*, a temperature from about 20 °C to about 30 °C.

The present invention also includes pharmaceutically acceptable salts of the compounds described herein. The term "pharmaceutically acceptable salts" refers to derivatives of the disclosed compounds wherein the parent compound is modified by converting an existing acid or base moiety to its salt form. Examples of pharmaceutically acceptable salts include, but are not limited to, mineral or organic acid salts of basic residues such as amines; alkali or organic salts of acidic residues such as carboxylic acids; and the like. The pharmaceutically acceptable salts of the present invention include the non-toxic salts of the parent compound formed, *e.g.*, from non-toxic inorganic or organic acids. The pharmaceutically acceptable salts of the present invention can be synthesized from the parent compound which contains a basic or acidic moiety by conventional chemical methods. Generally, such salts can be prepared by reacting the free acid or base forms of these compounds with a stoichiometric amount of the appropriate base or acid in water or in an organic solvent, or in a mixture of the two; generally, non-aqueous media like ether, ethyl acetate, alcohols (*e.g.*, methanol, ethanol, iso-propanol or butanol) or acetonitrile (MeCN) are preferred. Lists of suitable salts are found in *Remington's Pharmaceutical Sciences*, 17th Ed., (Mack Publishing Company, Easton, 1985), p. 1418, Berge *et al.*, *J. Pharm. Sci.*, **1977**, *66*(1), 1-19 and in Stahl *et al.*, *Handbook of Pharmaceutical Salts: Properties, Selection, and Use*, (Wiley, 2002). In some embodiments, the compounds described herein include the N-oxide forms.

*Synthesis*

Compounds of the present disclosure, including salts thereof, can be prepared using known organic synthesis techniques and can be synthesized according to any of numerous possible synthetic routes, such as those in the Schemes below.

The reactions for preparing compounds provided herein can be carried out in suitable solvents which can be readily selected by one of skill in the art of organic synthesis. Suitable solvents can be substantially nonreactive with the starting materials (reactants), the intermediates, or products at the temperatures at which the reactions are carried out, e.g., temperatures which can range from the solvent's freezing temperature to the solvent's boiling temperature. A given reaction can be carried out in one solvent or a mixture of more than one solvent. Depending on the particular reaction step, suitable solvents for a particular reaction step can be selected by the skilled artisan.

Preparation of compounds provided herein can involve the protection and deprotection of various chemical groups. The need for protection and deprotection, and the selection of appropriate protecting groups, can be readily determined by one skilled in the art. The chemistry of protecting groups can be found, for example, in T.W. Greene and P.G.M. Wuts, *Protective Groups in Organic Synthesis*, 3rd. Ed., Wiley & Sons, Inc., New York (1999), which is incorporated herein by reference in its entirety.

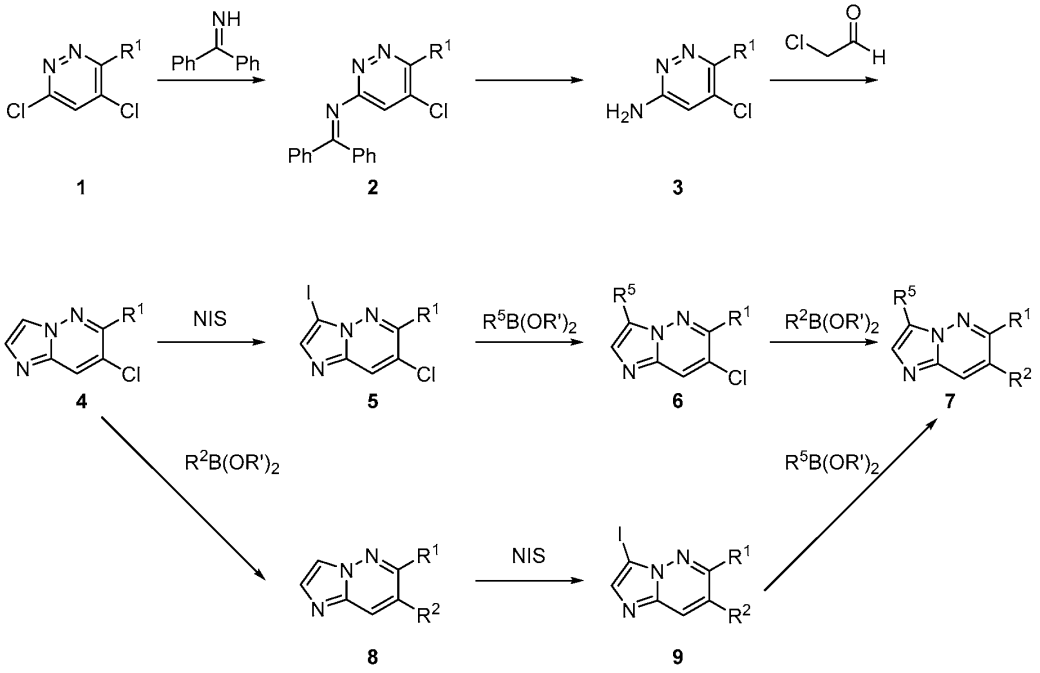
Reactions can be monitored according to any suitable method known in the art. For example, product formation can be monitored by spectroscopic means, such as nuclear magnetic resonance spectroscopy (e.g., $^{1}H$ or $^{13}C$), infrared spectroscopy, spectrophotometry (e.g., UV-visible), or mass spectrometry, or by chromatography such as high performance liquid chromatography (HPLC) or thin layer chromatography (TLC).

Compounds as disclosed herein can be prepared by one skilled in the art according to preparatory routes known in the literature and according to various possible synthetic routes. Example synthetic methods for preparing compounds of the present application are provided in the Schemes below.

A series of imidazo[1,2-b]pyridazine derivatives **7** can be prepared according to the procedure outlined in Scheme 1. Aminopyridazine **3** can be obtained by palladium catalytic amination (*Tetrahedron Lett.* **1997**, *38*, 6367-6370) of the dichloropyridazine **1** with diphenylmethanimine followed by hydrolysis under acidic conditions. Cycloaddition of the aminopyridazine **3** with 2-chloroacetaldehyde gives the imidazo[1,2-b]pyridazine **4** which can be converted to the corresponding imidazo[1,2-b]pyridazine iodide **5** by treatment with NIS. Suzuki coupling (*J. Am. Chem. Soc.* **2010**, *132*, 14073-14075) with the boronic acid or

ester $R^5B(OR')_2$ affords compound **6** which can be converted to the desired imidazo[1,2-b]pyridazine derivatives **7** by further Suzuki coupling with a suitable boronic acid or ester $R^2B(OR')_2$. Alternatively, Suzuki coupling of imidazo[1,2-b]pyridazine **4** with the boronic acid or ester $R^2B(OR')_2$ affords compound **8** which can be converted to compound **9** by treatment with NIS. The imidazo[1,2-b]pyridazine iodide **9** can be subsequently converted to the desired imidazo[1,2-b]pyridazine derivatives **7** by Suzuki coupling with a suitable boronic acid or ester $R^5B(OR')_2$.

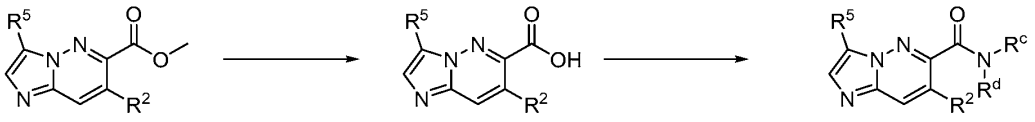
**Scheme 1**




A series of imidazo[1,2-b]pyridazine-6-carboxamide derivatives **12** can be prepared according to the procedure outlined in Scheme 2. Methyl imidazo[1,2-b]pyridazine-6-carboxylate **10** prepared according to the procedure outlined in Scheme 1 can be converted to the corresponding acid **11** by hydrolysis. The acid **11** can be subsequently converted to the desired imidazo[1,2-b]pyridazine-6-carboxamide derivatives **12** by coupling with an appropriate amine using an amidation coupling reagent such as, but not limited to, (benzotriazol-1-yloxy)tris(dimethylamino)phosphonium hexafluorophosphate (BOP), (benzotriazol-1-yloxy)tripyrrolidinophosphonium hexafluorophosphate(PyBOP), 1-[bis(dimethylamino)methylene]-1H-1,2,3-triazolo[4,5-b]pyridinium 3-oxid

hexafluorophosphate (HATU), or N,N,N',N'-tetramethyl-O-(1H-benzotriazol-1-yl)uronium hexafluorophosphate (HBTU).

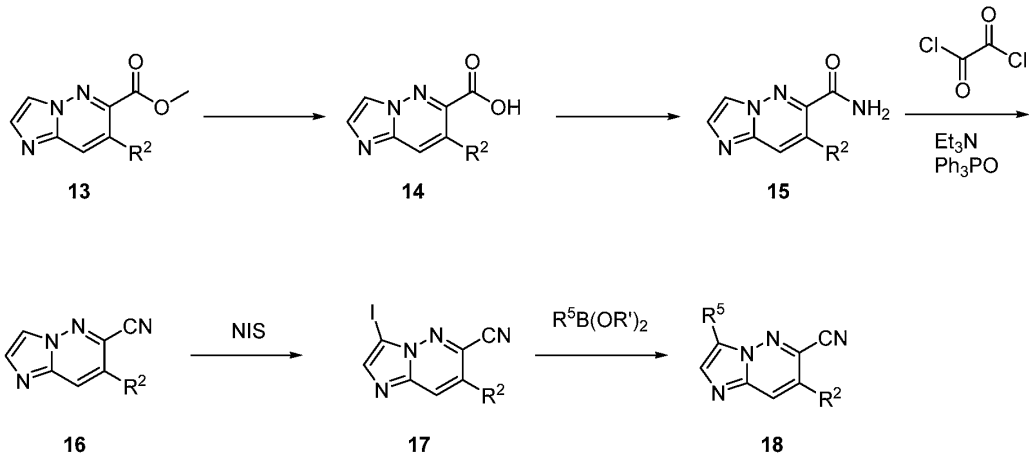
**Scheme 2**



10 11 12

A series of imidazo[1,2-b]pyridazine-6-carbonitrile derivatives **18** can be prepared according to the procedure outlined in Scheme 3. Methyl imidazo[1,2-b]pyridazine-6-carboxylate **13**, prepared according to the procedure outlined in Scheme 1, can be converted to the corresponding acid **14** by hydrolysis. The acid **14** can be subsequently converted to imidazo[1,2-b]pyridazine-6-carboxamide **15** by coupling with ammonium chloride using an amidation coupling reagent such as HATU. Treating compound **15** with oxalyl chloride in the presence of triethylamine and triphenylphosphine oxide can afford compound **16** which then can be converted to the corresponding iodide **17** by treatment with NIS. Suzuki coupling with a suitable boronic acid or ester $R^5B(OR')_2$ affords the desired imidazo[1,2-b]pyridazine-6-carbonitrile derivatives **18**.

**Scheme 3**



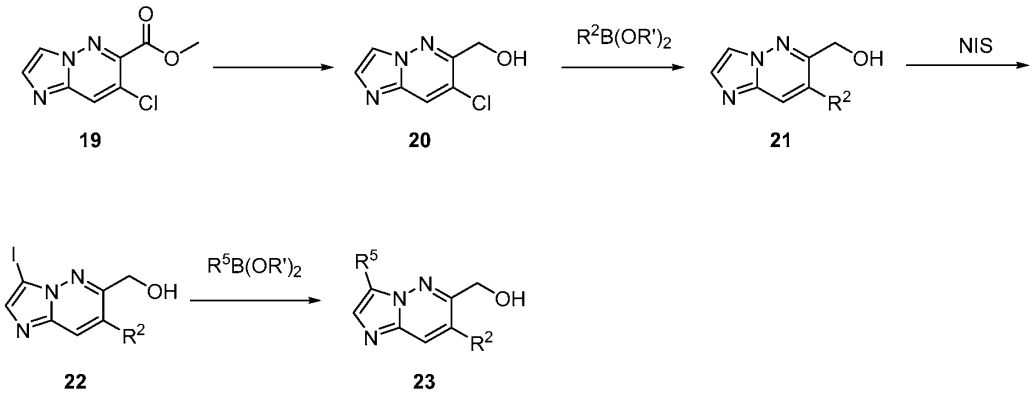
13 14 15

16 17 18

A series of imidazo[1,2-b]pyridazine derivatives **23** can be prepared according to the procedure outlined in Scheme 4. Methyl 7-chloroimidazo[1,2-b]pyridazine-6-carboxylate **19** prepared according to the procedure outlined in Scheme 1 can be converted to the

corresponding alcohol **20** by reduction. The alcohol **20** can be subsequently converted to compound **21** via Suzuki coupling with the boronic acid or ester $R^2B(OR')_2$. Treating compound **21** with NIS affords the corresponding iodide **22** which can be converted to the desired imidazo[1,2-b]pyridazine derivatives **23** through Suzuki coupling with a suitable boronic acid or ester $R^5B(OR')_2$.

**Scheme 4**




The invention will be described in greater detail by way of specific examples. The following examples are offered for illustrative purposes, and are not intended to limit the invention in any manner. Those of skill in the art will readily recognize a variety of non-critical parameters which can be changed or modified to yield essentially the same results. The compounds of the Examples were described as below.

*Methods of Use*

The present disclosure provides a method of modulating (e.g., inhibiting) ALK2 activity by contacting a compound of the invention (or salt thereof) with the ALK2. The contacting can be in vivo or in vitro. In some embodiments, the method of inhibiting ALK2 activity includes, for example, administering to a patient a compound provided herein, or a pharmaceutically acceptable salt thereof. The compounds of the present disclosure can be used alone, in combination with other agents or therapies or as an adjuvant or neoadjuvant for the treatment of diseases or disorders, including cancers. For the uses described herein, any of the compounds of the disclosure, including any of the embodiments thereof, may be used.

In myelofibrosis (MF), a significant proportion of patients develop anemia and become dependent on frequent red blood cell (RBC) transfusions (Tefferi, A. et al. Mayo Clinic Proceedings 2012 87, 25-33). Elevated serum hepcidin levels in patients with MF have

been shown to be associated with hemoglobin (Hb) levels, increased requirement for RBC transfusions and reduced survival (Pardanani, A. et al. American Journal of Hematology 2013, 88, 312-316). BMP signaling plays a central role in driving hepcidin transcriptional induction by activating SMAD signaling. In anemia mouse model, the liver-specific deletion of either ALK2 or ALK3 can block the induction of hepcidin production and iron overload (Steinbicker, A.U., et al. Blood 2011, 118, 4224-4230). Therefore, ALK2 inhibition could be useful in combination with ruxolitinib in the treatment of MF patients as the hepcidin-mediated FPN1 internalization and degradation may not require the action of JAK2 (Ross, S.L., et al. Cell Metabolism 2012, 15, 905-917). The ALK2 inhibition may block the negative effect of hepcidin on iron metabolism and improve the anemia in MF patients (Asshoff, M. et al. Blood 2017, 129, 1823-1830).

Fibrodysplasia ossificans progressiva (FOP) is a human rare genetic bone disease and the patients were characterized by extraskeletal bone formation through endochondral ossification (Yu, P.B., et al. Nature Medicine 2008, 14, 1363-1369; Fukuda, T. et al. Journal of Biological Chemistry 2009 284, 7149-7156). 95% of FOP patients harbor point mutations in ACVR1/ALK2 and The responsive mutation for classic FOP is 617G >A (R206H) in the intracellular glycine and serine-rich (GS) domain of ALK2 (Shen, Q. et al. Journal of Clinical Investigation 2009, 119, 3462-3472). ALK2 mutations in atypical FOP patients have also been found in other amino acids of the GS domain or protein kinase domain (Fukuda, T. et al. Biochemical and BiophysicalResearch Communications 2008, 377, 905-909). The different ALK2 mutants have been shown to activate BMP signaling without exogenous BMP ligands constitutively and these ALK2 mutants can transmit much stronger BMP signaling upon ligand stimulation (Van Dinther, M. et al. Journal of Bone and Mineral Research 2010, 25, 1208-1215).

Activating mutations in ALK2 have also been identified in diffuse intrapontine gliomas (DIPG), which are highly aggressive glial neoplasms of the ventral pons in the pediatric population. ALK2 was reported as one of the most recurrently mutated gene in DIPG. ALK2 was found to carry nonsynonymous heterozygous somatic mutations in 46 of 195 (24%) cases at five specific residues. Patients with ALK2 mutations were predominantly female (approximately 2:1) and had a younger age of onset (approximately 5 years) and longer overall survival time (approximately 15 months) compared with wild-type IDPG. These ALK2 mutants are highly specific to DIPG and the ALK2 inhibitor LDN-19318917 results in significant inhibition of those ALK2 mutant DIPG cell viability (Taylor, K.R. et al.

Nature Genetics 2014, 46, 457-461; Buczkowicz, P. et al. Nature Genetics 2014, 46, 451-456).

A method of treating a disease or disorder associated with expression or activity of ALK2 can include administering to a patient in need thereof a therapeutically effective amount of a compound provided herein, or a pharmaceutically acceptable salt thereof. In some embodiments, the disease or disorder is cancer. Examples of cancers that are treatable using the compounds of the present disclosure include, but are not limited to, bone cancer, pancreatic cancer, skin cancer, cancer of the head or neck, cutaneous or intraocular malignant melanoma, uterine cancer, ovarian cancer, rectal cancer, cancer of the anal region, stomach cancer, testicular cancer, uterine cancer, carcinoma of the fallopian tubes, carcinoma of the endometrium, endometrial cancer, carcinoma of the cervix, carcinoma of the vagina, carcinoma of the vulva, Hodgkin's Disease, non-Hodgkin's lymphoma, cancer of the esophagus, cancer of the small intestine, cancer of the endocrine system, cancer of the thyroid gland, cancer of the parathyroid gland, cancer of the adrenal gland, sarcoma of soft tissue, cancer of the urethra, cancer of the penis, chronic or acute leukemias including acute myeloid leukemia, chronic myeloid leukemia, acute lymphoblastic leukemia, chronic lymphocytic leukemia, solid tumors of childhood, lymphocytic lymphoma, cancer of the bladder, cancer of the kidney or urethra, carcinoma of the renal pelvis, neoplasm of the central nervous system (CNS), primary CNS lymphoma, tumor angiogenesis, spinal axis tumor, brain stem glioma, pituitary adenoma, Kaposi's sarcoma, epidermoid cancer, squamous cell cancer, T-cell lymphoma, environmentally induced cancers including those induced by asbestos, and combinations of said cancers.

In some embodiments, cancers treatable with compounds of the present disclosure include melanoma (e.g., metastatic malignant melanoma), renal cancer (e.g. clear cell carcinoma), prostate cancer (e.g. hormone refractory prostate adenocarcinoma), breast cancer, triple-negative breast cancer, colon cancer and lung cancer (e.g. non-small cell lung cancer and small cell lung cancer). Additionally, the disclosure includes refractory or recurrent malignancies whose growth may be inhibited using the compounds of the disclosure.

In some embodiments, cancers that are treatable using the compounds of the present disclosure include, but are not limited to, solid tumors (*e.g.*, prostate cancer, colon cancer, esophageal cancer, endometrial cancer, ovarian cancer, uterine cancer, renal cancer, hepatic cancer, pancreatic cancer, gastric cancer, breast cancer, lung cancer, cancers of the head and neck, thyroid cancer, glioblastoma, sarcoma, bladder cancer, etc.), hematological cancers

(*e.g.*, lymphoma, leukemia such as acute lymphoblastic leukemia (ALL), acute myelogenous leukemia (AML), chronic lymphocytic leukemia (CLL), chronic myelogenous leukemia (CML), DLBCL, mantle cell lymphoma, Non-Hodgkin lymphoma (including relapsed or refractory NHL and recurrent follicular), Hodgkin lymphoma or multiple myeloma) and combinations of said cancers.

In some embodiments, diseases and indications that are treatable using the compounds of the present disclosure include, but are not limited to hematological cancers, sarcomas, lung cancers, gastrointestinal cancers, genitourinary tract cancers, liver cancers, bone cancers, nervous system cancers, gynecological cancers, and skin cancers.

Exemplary hematological cancers include lymphomas and leukemias such as acute lymphoblastic leukemia (ALL), acute myelogenous leukemia (AML), acute promyelocytic leukemia (APL), chronic lymphocytic leukemia (CLL), chronic myelogenous leukemia (CML), diffuse large B-cell lymphoma (DLBCL), mantle cell lymphoma, Non-Hodgkin lymphoma (including relapsed or refractory NHL and recurrent follicular), Hodgkin lymphoma, myeloproliferative diseases (e.g., primary myelofibrosis (PMF), polycythemia vera (PV), essential thrombocytosis (ET)), myelodysplasia syndrome (MDS), T-cell acute lymphoblastic lymphoma (T-ALL), multiple myeloma, cutaneous T-cell lymphoma, Waldenstrom's Macroglubulinemia, hairy cell lymphoma, chronic myelogenic lymphoma and Burkitt's lymphoma.

Exemplary sarcomas include chondrosarcoma, Ewing's sarcoma, osteosarcoma, rhabdomyosarcoma, angiosarcoma, fibrosarcoma, liposarcoma, myxoma, rhabdomyoma, rhabdosarcoma, fibroma, lipoma, harmatoma, and teratoma. Exemplary sarcomas also include lymphosarcoma and leiomyosarcoma.

Exemplary lung cancers include non-small cell lung cancer (NSCLC), small cell lung cancer, bronchogenic carcinoma (squamous cell, undifferentiated small cell, undifferentiated large cell, adenocarcinoma), alveolar (bronchiolar) carcinoma, bronchial adenoma, chondromatous hamartoma, and mesothelioma. Exemplary lung cancers also include pavicellular and non-pavicellular carcinoma, bronchial adenoma and pleuropulmonary blastoma.

Exemplary gastrointestinal cancers include cancers of the esophagus (squamous cell carcinoma, adenocarcinoma, leiomyosarcoma, lymphoma), stomach (carcinoma, lymphoma, leiomyosarcoma), pancreas (exocrine pancreatic carcinoma, ductal adenocarcinoma, insulinoma, glucagonoma, gastrinoma, carcinoid tumors, vipoma), small bowel (adenocarcinoma, lymphoma, carcinoid tumors, Kaposi's sarcoma, leiomyoma, hemangioma,

lipoma, neurofibroma, fibroma), large bowel (adenocarcinoma, tubular adenoma, villous adenoma, hamartoma, leiomyoma), and colorectal cancer. Exemplary gastrointestinal cancers also include gall bladder cancer and anal cancer.

Exemplary genitourinary tract cancers include cancers of the kidney (adenocarcinoma, Wilm's tumor [nephroblastoma]), bladder and urethra (squamous cell carcinoma, transitional cell carcinoma, adenocarcinoma), prostate (adenocarcinoma, sarcoma), and testis (seminoma, teratoma, embryonal carcinoma, teratocarcinoma, choriocarcinoma, sarcoma, interstitial cell carcinoma, fibroma, fibroadenoma, adenomatoid tumors, lipoma). Exemplary genitourinary tract cancers also include renal cell carcinoma and urothelial carcinoma.

Exemplary liver cancers include hepatoma (hepatocellular carcinoma), cholangiocarcinoma, hepatoblastoma, angiosarcoma, hepatocellular adenoma, and hemangioma.

Exemplary bone cancers include, for example, osteogenic sarcoma (osteosarcoma), fibrosarcoma, malignant fibrous histiocytoma, chondrosarcoma, Ewing's sarcoma, malignant lymphoma (reticulum cell sarcoma), multiple myeloma, malignant giant cell tumor chordoma, osteochronfroma (osteocartilaginous exostoses), benign chondroma, chondroblastoma, chondromyxofibroma, osteoid osteoma, and giant cell tumors

Exemplary nervous system cancers include cancers of the skull (osteoma, hemangioma, granuloma, xanthoma, osteitis deformans), meninges (meningioma, meningiosarcoma, gliomatosis), brain (astrocytoma, meduoblastoma, glioma, ependymoma, germinoma (pinealoma), glioblastoma, glioblastoma multiform, oligodendroglioma, schwannoma, retinoblastoma, congenital tumors), and spinal cord (neurofibroma, meningioma, glioma, sarcoma), as well as neuroblastoma and Lhermitte-Duclos disease. Exemplary nervous system cancers also include neuro-ectodermal tumors and pineal tumors.

Exemplary gynecological cancers include cancers of the uterus (endometrial carcinoma), cervix (cervical carcinoma, pre -tumor cervical dysplasia), ovaries (ovarian carcinoma (serous cystadenocarcinoma, mucinous cystadenocarcinoma, unclassified carcinoma), granulosa-thecal cell tumors, Sertoli-Leydig cell tumors, dysgerminoma, malignant teratoma), vulva (squamous cell carcinoma, intraepithelial carcinoma, adenocarcinoma, fibrosarcoma, melanoma), vagina (clear cell carcinoma, squamous cell carcinoma, botryoid sarcoma (embryonal rhabdomyosarcoma), and fallopian tubes (carcinoma). Exemplary nervous system cancers also include neuro-ectodermal tumors and pineal tumors.

Exemplary skin cancers include melanoma, basal cell carcinoma, squamous cell carcinoma, Kaposi's sarcoma, Merkel cell skin cancer, moles dysplastic nevi, lipoma, angioma, dermatofibroma, and keloids. In some embodiments, diseases and indications that are treatable using the compounds of the present disclosure include, but are not limited to, sickle cell disease (e.g., sickle cell anemia), triple-negative breast cancer (TNBC), myelodysplastic syndromes, testicular cancer, bile duct cancer, esophageal cancer, and urothelial carcinoma.

Exemplary head and neck cancers include glioblastoma, melanoma, rhabdosarcoma, lymphosarcoma, osteosarcoma, squamous cell carcinomas, adenocarcinomas, oral cancer, laryngeal cancer, nasopharyngeal cancer, nasal and paranasal cancers, thyroid and parathyroid cancers. Exemplary head and neck cancers also include tumors of the eye, tumors of the lips and mouth and squamous head and neck cancer.

The compounds of the present disclosure can also be useful in the inhibition of tumor metastases. In some embodiments, the compounds provided herein may be used to treat tumors producing PGE2 (e.g. Cox-2 overexpressing tumors) and/or adenosine (CD73 and CD39 over-expressing tumors). Overexpression of Cox-2 has been detected in a number of tumors, such as colorectal, breast, pancreatic and lung cancers, where it correlates with a poor prognosis. Overexpression of Cox-2 has been reported in hematological cancer models such as RAJI (Burkitt's lymphoma) and U937 (acute promonocytic leukemia) as well as in patient's blast cells. CD73 is up-regulated in various human carcinomas including those of colon, lung, pancreas and ovary. Importantly, higher expression levels of CD73 are associated with tumor neovascularization, invasiveness, and metastasis and with shorter patient survival time in breast cancer.

The terms "individual" or "patient," used interchangeably, refer to any animal, including mammals, preferably mice, rats, other rodents, rabbits, dogs, cats, swine, cattle, sheep, horses, or primates, and most preferably humans.

The phrase "therapeutically effective amount" refers to the amount of active compound or pharmaceutical agent that elicits the biological or medicinal response in a tissue, system, animal, individual or human that is being sought by a researcher, veterinarian, medical doctor or other clinician.

As used herein, the term "treating" or "treatment" refers to one or more of (1) inhibiting the disease; *e.g.*, inhibiting a disease, condition or disorder in an individual who is experiencing or displaying the pathology or symptomatology of the disease, condition or disorder (*i.e.*, arresting further development of the pathology and/or symptomatology); and

(2) ameliorating the disease; *e.g.*, ameliorating a disease, condition or disorder in an individual who is experiencing or displaying the pathology or symptomatology of the disease, condition or disorder (*i.e.*, reversing the pathology and/or symptomatology) such as decreasing the severity of disease.

As used herein, the term "contacting" refers to the bringing together of the indicated compounds in an in vitro system or an in vivo system such that they are in sufficient physical proximity to interact.

In some embodiments, the compounds of the present disclosure are useful in preventing or reducing the risk of developing any of the diseases referred to herein; *e.g.*, preventing or reducing the risk of developing a disease, condition or disorder in an individual who may be predisposed to the disease, condition or disorder but does not yet experience or display the pathology or symptomatology of the disease.

*Combination Therapies*

One or more additional pharmaceutical agents or treatment methods such as, for example, anti-viral agents, chemotherapeutics or other anti-cancer agents, immune enhancers, immunosuppressants, radiation, anti-tumor and anti-viral vaccines, cytokine therapy (e.g., IL2, GM-CSF, etc.), and/or tyrosine kinase inhibitors can be used in combination with compounds described herein for treatment of ALK2 associated diseases, disorders or conditions, or diseases or conditions as described herein. The agents can be combined with the present compounds in a single dosage form, or the agents can be administered simultaneously or sequentially as separate dosage forms.

*I. Immune-checkpoint therapies*

In some embodiments, the compounds provided herein can be used in combination with one or more immune checkpoint inhibitors for the treatment of cancer as described herein. Compounds of the present disclosure can be used in combination with one or more immune checkpoint inhibitors. Exemplary immune checkpoint inhibitors include inhibitors against immune checkpoint molecules such as CD20, CD28, CD39, CD40, CD122, CD96, CD73, CD47, GITR, CSF1R, JAK, PI3K delta, PI3K gamma, TAM, arginase, CD137 (also known as 4-1BB), ICOS, B7-H3, B7-H4, BTLA, CTLA-4, LAG3, TIM3, VISTA, TIGIT, PD-1, PD-L1 and PD-L2. In some embodiments, the immune checkpoint molecule is a stimulatory checkpoint molecule selected from CD27, CD28, CD40, ICOS, OX40, GITR and CD137. In some embodiments, the immune checkpoint molecule is an inhibitory checkpoint

molecule selected from A2AR, B7-H3, B7-H4, BTLA, CTLA-4, IDO, KIR, LAG3, PD-1, TIM3, TIGIT, and VISTA. In some embodiments, the compounds of the disclosure provided herein can be used in combination with one or more agents selected from KIR inhibitors, TIGIT inhibitors, LAIR1 inhibitors, CD160 inhibitors, 2B4 inhibitors and TGFR beta inhibitors.

In some embodiments, the compounds provided herein can be used in combination with one or more agonists of immune checkpoint molecules, e.g., OX40, CD27, GITR, and CD137 (also known as 4-1BB).

In some embodiments, the inhibitor of an immune checkpoint molecule is anti-PD1 antibody, anti-PD-L1 antibody, or anti-CTLA-4 antibody.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of PD-1, e.g., an anti-PD-1 monoclonal antibody. In some embodiments, the anti-PD-1 monoclonal antibody is nivolumab, pembrolizumab (also known as MK-3475), durvalumab (Imfinzi®), pidilizumab, SHR-1210, PDR001, MGA012, PDR001, AB122, or AMP-224. In some embodiments, the anti-PD-1 monoclonal antibody is nivolumab or pembrolizumab. In some embodiments, the anti-PD1 antibody is pembrolizumab. In some embodiments, the anti-PD-1 monoclonal antibody is MGA012. In some embodiments, the anti-PD1 antibody is SHR-1210. Other anti-cancer agent(s) include antibody therapeutics such as 4-1BB (e.g. urelumab, utomilumab). In some embodiments, the anti-PD-1 monoclonal antibody is ipilumimab.

In some embodiments, the compounds of the disclosure can be used in combination with INCB086550.

In some embodiments, the inhibitor of an immune checkpoint molecule is anti-PD1 antibody, anti-a small molecule PD-L1 antibody, or anti-CTLA-4 antibody.inhibitor. In some embodiments, the small molecule PD-L1 inhibitor has an $IC_{50}$ less than 1 μM, less than 100 nM, less than 10 nM or less than 1 nM in a PD-L1 assay described in US Patent Publication Nos. US 20170107216, US 20170145025, US 20170174671, US 20170174679, US 20170320875, US 20170342060, US 20170362253, US 20180016260, US 20180057486, US 20180177784, US 20180177870, US 20180179179, US 20180179197, US 20180179201, and US 20180179202, each of which is incorporated by reference in its entirety for all purposes.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of PD-L1, e.g., an anti-PD-L1 monoclonal antibody. In some embodiments, the anti-PD-L1 monoclonal antibody is BMS-935559, MEDI4736, MPDL3280A (also known as RG7446),

or MSB0010718C. In some embodiments, the anti-PD-L1 monoclonal antibody is MPDL3280A or MEDI4736.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of PD-1 and PD-L1, e.g., an anti-PD-1/PD-L1 monoclonal antibody. In some embodiments, the anti-PD-1/PD-L1 is MCLA-136.

In some embodiments, the inhibitor is MCLA-145.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of CTLA-4, e.g., an anti-CTLA-4 antibody. In some embodiments, the anti-CTLA-4 antibody is ipilimumab, tremelimumab, AGEN1884, or CP-675,206.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of CSF1R, e.g., an anti- CSF1R antibody. In some embodiments, the anti- CSF1R antibody is IMC-CS4 or RG7155.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of LAG3, e.g., an anti-LAG3 antibody. In some embodiments, the anti-LAG3 antibody is BMS-986016, LAG525, IMP321, GSK2831781, or INCAGN2385.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of TIM3, e.g., an anti-TIM3 antibody. In some embodiments, the anti-TIM3 antibody is INCAGN2390, MBG453, or TSR-022.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of GITR, e.g., an anti-GITR antibody. In some embodiments, the anti-GITR antibody is TRX518, MK-4166, INCAGN1876, MK-1248, AMG228, BMS-986156, GWN323, or MEDI1873.

In some embodiments, the inhibitor of an immune checkpoint molecule is an agonist of OX40, e.g., OX40 agonist antibody or OX40L fusion protein. In some embodiments, the anti-OX40 antibody is MEDI0562, MEDI6469, MOXR-0916, PF-04518600, GSK3174998, or BMS-986178. In some embodiments, the OX40L fusion protein is MEDI6383.

In some embodiments, the inhibitor of an immune checkpoint molecule is an inhibitor of CD20, e.g., an anti-CD20 antibody. In some embodiments, the anti-CD20 antibody is obinutuzumab or rituximab.

The compounds of the present disclosure can be used in combination with bispecific antibodies. In some embodiments, one of the domains of the bispecific antibody targets PD-1, PD-L1, CTLA-4, GITR, OX40, TIM3, LAG3, CD137, ICOS, CD3 or TGFβ receptor.

In some embodiments, the compounds of the disclosure can be used in combination with one or more metabolic enzyme inhibitors. In some embodiments, the metabolic enzyme

inhibitor is an inhibitor of IDO1, TDO, or arginase. Examples of IDO1 inhibitors include epacadostat, NLG919, BMS-986205, PF-06840003, IOM2983, RG-70099 and LY338196. An example of an arginase inhibitor is CB-1158.

As provided throughout, the additional compounds, inhibitors, agents, etc. can be combined with the present compound in a single or continuous dosage form, or they can be administered simultaneously or sequentially as separate dosage forms.

*II. Cancer therapies*

Cancer cell growth and survival can be impacted by multiple signaling pathways. Thus, it is useful to combine different enzyme/protein/receptor inhibitors, exhibiting different preferences in the targets which they modulate the activities of, to treat such conditions. Examples of agents that may be combined with compounds of the present disclosure include inhibitors of the PI3K-AKT-mTOR pathway, inhibitors of the Raf-MAPK pathway, inhibitors of JAK-STAT pathway, inhibitors of beta catenin pathway, inhibitors of notch pathway, inhibitors of hedgehog pathway, inhibitors of Pim kinases, and inhibitors of protein chaperones and cell cycle progression. Targeting more than one signaling pathway (or more than one biological molecule involved in a given signaling pathway) may reduce the likelihood of drug-resistance arising in a cell population, and/or reduce the toxicity of treatment.

The compounds of the present disclosure can be used in combination with one or more other enzyme/protein/receptor inhibitors for the treatment of diseases, such as cancer. Examples of cancers include solid tumors and liquid tumors, such as blood cancers. For example, the compounds of the present disclosure can be combined with one or more inhibitors of the following kinases for the treatment of cancer: Akt1, Akt2, Akt3, TGF-βR, Pim, PKA, PKG, PKC, CaM-kinase, phosphorylase kinase, MEKK, ERK, MAPK, mTOR, EGFR, HER2, HER3, HER4, INS-R, IGF-1R, IR-R, PDGFαR, PDGFβR, CSFIR, KIT, FLK-II, KDR/FLK-1, FLK-4, flt-1, FGFR1, FGFR2, FGFR3, FGFR4, HPK, c-Met, Ron, Sea, TRKA, TRKB, TRKC, FLT3, VEGFR/Flt2, Flt4, EphA1, EphA2, EphA3, EphB2, EphB4, Tie2, Src, Fyn, Lck, Fgr, Btk, Fak, SYK, FRK, JAK, ABL, and B-Raf. In some embodiments, the compounds of the present disclosure can be combined with one or more of the following inhibitors for the treatment of cancer. Non-limiting examples of inhibitors that can be combined with the compounds of the present disclosure for treatment of cancers include an FGFR inhibitor (FGFR1, FGFR2, FGFR3 or FGFR4, e.g., AZD4547, BAY1187982, ARQ087, BGJ398, BIBF1120, TKI258, lucitanib, dovitinib, TAS-120, JNJ-

42756493, Debio1347, INCB54828, INCB62079 and INCB63904), a JAK inhibitor or Janus kinase inhibitor (JAK1 and/or JAK2, e.g., ruxolitinib, baricitinib tofacitinib, INCB39110, CYT387, GLPG0634, lestaurtinib, pacritinib, TG101348, or a JAK1-selective inhibitor), an IDO inhibitor (e.g., epacadostat and NLG919), an LSD1 inhibitor (e.g., GSK2979552, INCB59872 and INCB60003), a TDO inhibitor, a PI3K-delta inhibitor (e.g., INCB50797 and INCB50465), a PI3K-gamma inhibitor such as a PI3K-gamma selective inhibitor, a CSF1R inhibitor (e.g., PLX3397 and LY3022855), a TAM receptor tyrosine kinases (Tyro-3, Axl, and Mer), an angiogenesis inhibitor, an interleukin receptor inhibitor, bromo and extra terminal family members inhibitors (for example, bromodomain inhibitors or BET inhibitors such as OTX015, CPI-0610, INCB54329 and INCB57643) and an adenosine receptor antagonist or combinations thereof. Inhibitors of HDAC such as panobinostat and vorinostat. Inhibitors of c-Met such as onartumzumab, tivantnib, and INC-280. Inhibitors of BTK such as ibrutinib. Inhibitors of mTOR such as rapamycin, sirolimus, temsirolimus, and everolimus. Inhibitors of Raf, such as vemurafenib and dabrafenib. Inhibitors of MEK such as trametinib, selumetinib and GDC-0973. Inhibitors of Hsp90 (e.g., tanespimycin), cyclin dependent kinases (e.g., palbociclib), PARP (e.g., olaparib) and Pim kinases (LGH447, INCB053914 and SGI-1776) can also be combined with compounds of the present disclosure.

In some embodiments, a Janus kinase inhibitor may include ruxolitinib, tofacitinib, baricitinib, CYT387, GLPG0634, lestaurtinib, pacritinib, TG101348, or a JAK1-selective inhibitor.

In some embodiments, a Janus kinase inhibitor may include, tofacitinib, baricitinib, CYT387, GLPG0634, lestaurtinib, pacritinib, TG101348, or a JAK1-selective inhibitor.

In some embodiments, compounds of the present disclosure can be combined with one or more Janus kinase (JAK) inhibitors (JAK1 and/or JAK2, e.g., ruxolitinib, baricitinib or itacitinib). In some embodiments, compounds of the present disclosure can be combined with one or more JAK inhibitors (JAK1 and/or JAK2, e.g., ruxolitinib, baricitinib or itacitinib) for the treatment of cancers such as myeloproliferative diseases. For example, the myeloproliferative disease is myelofibrosis. In some embodiments, compounds of the present disclosure can be combined with ruxolitinib, or a pharmaceutically acceptable salt thereof. In some embodiments, compounds of the present disclosure can be combined with ruxolitinib, or a pharmaceutically acceptable salt thereof, for the treatment of myeloproliferative disease such as myleofibrosis.

Compounds of the present disclosure can be used in combination with one or more agents for the treatment of diseases such as cancer. In some embodiments, the agent is an

alkylating agent, a proteasome inhibitor, a corticosteroid, or an immunomodulatory agent. Examples of an alkylating agent include bendamustine, nitrogen mustards, ethylenimine derivatives, alkyl sulfonates, nitrosoureas and triazenes, uracil mustard, chlormethine, cyclophosphamide (CytoxanTM), ifosfamide, melphalan, chlorambucil, pipobroman, triethylene-melamine, triethylenethiophosphoramine, busulfan, carmustine, lomustine, streptozocin, dacarbazine, and temozolomide. In some embodiments, the proteasome inhibitor is carfilzomib. In some embodiments, the corticosteroid is dexamethasone (DEX). In some embodiments, the immunomodulatory agent is lenalidomide (LEN) or pomalidomide (POM).

The compounds of the present disclosure can further be used in combination with other methods of treating cancers, for example by chemotherapy, irradiation therapy, tumor-targeted therapy, adjuvant therapy, immunotherapy or surgery. Examples of immunotherapy include cytokine treatment (e.g., interferons, GM-CSF, G-CSF, IL-2), CRS-207 immunotherapy, cancer vaccine, monoclonal antibody, adoptive T cell transfer, CAR (Chimeric antigen receptor) T cell treatment as a booster for T cell activation, oncolytic virotherapy and immunomodulating small molecules, including thalidomide or JAK1/2 inhibitor and the like. The compounds can be administered in combination with one or more anti-cancer drugs, such as a chemotherapeutics. Example chemotherapeutics include any of: abarelix, abiraterone, afatinib, aflibercept, aldesleukin, alemtuzumab, alitretinoin, allopurinol, altretamine, amsacrine, anastrozole, aphidicolon, arsenic trioxide, asparaginase, axitinib, azacitidine, bevacizumab, bexarotene, baricitinib, bicalutamide, bleomycin, bortezombi, bortezomib, brivanib, buparlisib, busulfan intravenous, busulfan oral, calusterone, camptosar, capecitabine, carboplatin, carmustine, cediranib, cetuximab, chlorambucil, cisplatin, cladribine, clofarabine, crizotinib, cyclophosphamide, cytarabine, dacarbazine, dacomitinib, dactinomycin, dalteparin sodium, dasatinib, dactinomycin, daunorubicin, decitabine, degarelix, denileukin, denileukin diftitox, deoxycoformycin, dexrazoxane, docetaxel, doxorubicin, droloxafine, dromostanolone propionate, eculizumab, enzalutamide, epidophyllotoxin, epirubicin, epothilones, erlotinib, estramustine, etoposide phosphate, etoposide, exemestane, fentanyl citrate, filgrastim, floxuridine, fludarabine, fluorouracil, flutamide, fulvestrant, gefitinib, gemcitabine, gemtuzumab ozogamicin, goserelin acetate, histrelin acetate, ibritumomab tiuxetan, idarubicin, idelalisib, ifosfamide, imatinib mesylate, interferon alfa 2a, irinotecan, lapatinib ditosylate, lenalidomide, letrozole, leucovorin, leuprolide acetate, levamisole, lomustine, meclorethamine, megestrol acetate, melphalan, mercaptopurine, methotrexate, methoxsalen, mithramycin, mitomycin C,

mitotane, mitoxantrone, nandrolone phenpropionate, navelbene, necitumumab, nelarabine, neratinib, nilotinib, nilutamide, nofetumomab, oserelin, oxaliplatin, paclitaxel, pamidronate, panitumumab, pazopanib, pegaspargase, pegfilgrastim, pemetrexed disodium, pentostatin, pilaralisib, pipobroman, plicamycin, ponatinib, porfimer, prednisone, procarbazine, quinacrine, ranibizumab, rasburicase, regorafenib, reloxafine, revlimid, rituximab, ruxolitinib, sorafenib, streptozocin, sunitinib, sunitinib maleate, tamoxifen, tegafur, temozolomide, teniposide, testolactone, thalidomide, thioguanine, thiotepa, topotecan, toremifene, tositumomab, trastuzumab, tretinoin, triptorelin, uracil mustard, valrubicin, vandetanib, vinblastine, vincristine, vindesine, vinorelbine, vorinostat and zoledronate.

Other anti-cancer agent(s) include antibody therapeutics such as trastuzumab (Herceptin), antibodies to costimulatory molecules such as CTLA-4 (e.g., ipilimumab or tremelimumab), 4-1BB, antibodies to PD-1 and PD-L1, or antibodies to cytokines (IL-10, TGF-β, etc.). Examples of antibodies to PD-1 and/or PD-L1 that can be combined with compounds of the present disclosure for the treatment of cancer or infections such as viral, bacteria, fungus and parasite infections include, but are not limited to, nivolumab, pembrolizumab, MPDL3280A, MEDI-4736 and SHR-1210.

Other anti-cancer agents include inhibitors of kinases associated cell proliferative disorder. These kinases include but not limited to Aurora-A, CDK1, CDK2, CDK3, CDK5, CDK7, CDK8, CDK9, ephrin receptor kinases, CHK1, CHK2, SRC, Yes, Fyn, Lck, Fer, Fes, Syk, Itk, Bmx, GSK3, JNK, PAK1, PAK2, PAK3, PAK4, PDK1, PKA, PKC, Rsk and SGK.

Other anti-cancer agents also include those that block immune cell migration such as antagonists to chemokine receptors, including CCR2 and CCR4.

The compounds of the present disclosure can further be used in combination with one or more anti-inflammatory agents, steroids, immunosuppressants or therapeutic antibodies. The steroids include but are not limited to 17 alpha-ethinylestradiol, diethylstilbestrol, testosterone, prednisone, fluoxymesterone, methylprednisolone, methyltestosterone, prednisolone, triamcinolone, chlorotrianisene, hydroxyprogesterone, aminoglutethimide, and medroxyprogesteroneacetate.

The compounds of the present disclosure can also be used in combination with lonafarnib (SCH6636), tipifarnib (R115777), L778123, BMS 214662, tezacitabine (MDL 101731), SmL1, triapine, didox, trimidox and amidox.

The compounds described herein can be combined with another immunogenic agent, such as cancerous cells, purified tumor antigens (including recombinant proteins, peptides, and carbohydrate molecules), cells, and cells transfected with genes encoding immune

stimulating cytokines. Non-limiting examples of tumor vaccines that can be used include peptides of melanoma antigens, such as peptides of gp100, MAGE antigens, Trp-2, MARTI and/or tyrosinase, or tumor cells transfected to express the cytokine GM-CSF.

The compounds described herein can be used in combination with a vaccination protocol for the treatment of cancer. In some embodiments, the tumor cells are transduced to express GM-CSF. In some embodiments, tumor vaccines include the proteins from viruses implicated in human cancers such as Human Papilloma Viruses (HPV), Hepatitis Viruses (HBV and HCV) and Kaposi's Herpes Sarcoma Virus (KHSV). In some embodiments, the compounds of the present disclosure can be used in combination with tumor specific antigen such as heat shock proteins isolated from tumor tissue itself. In some embodiments, the compounds described herein can be combined with dendritic cells immunization to activate potent anti-tumor responses.

The compounds of the present disclosure can be used in combination with bispecific macrocyclic peptides that target Fe alpha or Fe gamma receptor-expressing effectors cells to tumor cells. The compounds of the present disclosure can also be combined with macrocyclic peptides that activate host immune responsiveness.

The compounds of the present disclosure can be used in combination with bone marrow transplant for the treatment of a variety of tumors of hematopoietic origin.

Suitable antiviral agents contemplated for use in combination with the compounds of the present disclosure can comprise nucleoside and nucleotide reverse transcriptase inhibitors (NRTIs), non-nucleoside reverse transcriptase inhibitors (NNRTIs), protease inhibitors and other antiviral drugs.

Example suitable NRTIs include zidovudine (AZT); didanosine (ddl); zalcitabine (ddC); stavudine (d4T); lamivudine (3TC); abacavir (1592U89); adefovir dipivoxil [bis(POM)-PMEA]; lobucavir (BMS-180194); BCH-10652; emitricitabine [(-)-FTC]; beta-L-FD4 (also called beta-L-D4C and named beta-L-2', 3'-dicleoxy-5-fluoro-cytidene); DAPD, ((-)-beta-D-2,6,-diamino-purine dioxolane); and lodenosine (FddA). Typical suitable NNRTIs include nevirapine (BI-RG-587); delaviradine (BHAP, U-90152); efavirenz (DMP-266); PNU-142721; AG-1549; MKC-442 (1-(ethoxy-methyl)-5-(1-methylethyl)-6-(phenylmethyl)-(2,4(1H,3H)-pyrimidinedione); and (+)-calanolide A (NSC-675451) and B. Typical suitable protease inhibitors include saquinavir (Ro 31-8959); ritonavir (ABT-538); indinavir (MK-639); nelfnavir (AG-1343); amprenavir (141W94); lasinavir (BMS-234475); DMP-450; BMS-2322623; ABT-378; and AG-1 549. Other antiviral agents include hydroxyurea, ribavirin, IL-2, IL-12, pentafuside and Yissum Project No.11607.

The compounds described herein may be combined with or in sequence with other agents against membrane receptor kinases especially for patients who have developed primary or acquired resistance to the targeted therapy. These therapeutic agents include inhibitors or antibodies against EGFR, Her2, VEGFR, c-Met, Ret, IGFR1, or Flt-3 and against cancer-associated fusion protein kinases such as Bcr-Abl and EML4-Alk. Inhibitors against EGFR include gefitinib and erlotinib, and inhibitors against EGFR/Her2 include but are not limited to dacomitinib, afatinib, lapitinib and neratinib. Antibodies against the EGFR include but are not limited to cetuximab, panitumumab and necitumumab. Inhibitors of c-Met may be used in combination with compound disclosed herein. These include onartumzumab, tivantnib, and capmatinib. Agents against Abl (or Bcr-Abl) include imatinib, dasatinib, nilotinib, and ponatinib and those against Alk (or EML4-ALK) include crizotinib.

Angiogenesis inhibitors may be efficacious in some tumors in combination with compounds disclosed herein. These include antibodies against VEGF or VEGFR or kinase inhibitors of VEGFR. Antibodies or other therapeutic proteins against VEGF include bevacizumab and aflibercept. Inhibitors of VEGFR kinases and other anti-angiogenesis inhibitors include but are not limited to sunitinib, sorafenib, axitinib, cediranib, pazopanib, regorafenib, brivanib, and vandetanib

Activation of intracellular signaling pathways is frequent in cancer, and agents targeting components of these pathways have been combined with receptor targeting agents to enhance efficacy and reduce resistance. Examples of agents that may be combined with compounds described herein include inhibitors of the PI3K-AKT-mTOR pathway, inhibitors of the Raf-MAPK pathway, inhibitors of JAK-STAT pathway, and inhibitors of protein chaperones and cell cycle progression.

Agents against the PI3 kinase include but are not limited topilaralisib, idelalisib, buparlisib. Inhibitors of mTOR such as rapamycin, sirolimus, temsirolimus, and everolimus may be combined with compounds of the invention. Other suitable examples include but are not limited to vemurafenib and dabrafenib (Raf inhibitors) and trametinib, selumetinib and GDC-0973 (MEK inhibitors). Inhibitors of one or more JAKs (e.g., ruxolitinib, baricitinib, tofacitinib), Hsp90 (e.g., tanespimycin), cyclin dependent kinases (e.g., palbociclib), HDACs (e.g., panobinostat), PARP (e.g., olaparib), and proteasomes (e.g., bortezomib, carfilzomib) can also be combined with compounds described herein. In some embodiments, the JAK inhibitor is selective for JAK1 over JAK2 and JAK3.

Other suitable agents for use in combination with compounds described herein include chemotherapy combinations such as platinum-based doublets used in lung cancer and

other solid tumors (cisplatin or carboplatin plus gemcitabine; cisplatin or carboplatin plus docetaxel; cisplatin or carboplatin plus paclitaxel; cisplatin or carboplatin plus pemetrexed) or gemcitabine plus paclitaxel bound particles (Abraxane®).

Suitable chemotherapeutic or other anti-cancer agents include, for example, alkylating agents (including, without limitation, nitrogen mustards, ethylenimine derivatives, alkyl sulfonates, nitrosoureas and triazenes) such as uracil mustard, chlormethine, cyclophosphamide (Cytoxan™), ifosfamide, melphalan, chlorambucil, pipobroman, triethylene-melamine, triethylenethiophosphoramine, busulfan, carmustine, lomustine, streptozocin, dacarbazine, and temozolomide.

Other suitable agents for use in combination with compounds described herein include steroids including 17 alpha-ethinylestradiol, diethylstilbestrol, testosterone, prednisone, fluoxymesterone, methylprednisolone, methyltestosterone, prednisolone, triamcinolone, chlorotrianisene, hydroxyprogesterone, aminoglutethimide, and medroxyprogesteroneacetate.

Other suitable agents for use in combination with compounds described herein include: dacarbazine (DTIC), optionally, along with other chemotherapy drugs such as carmustine (BCNU) and cisplatin; the "Dartmouth regimen," which consists of DTIC, BCNU, cisplatin and tamoxifen; a combination of cisplatin, vinblastine, and DTIC; or temozolomide. Compounds described herein may also be combined with immunotherapy drugs, including cytokines such as interferon alpha, interleukin 2, and tumor necrosis factor (TNF) inhibitors.

Suitable chemotherapeutic or other anti-cancer agents include, for example, antimetabolites (including, without limitation, folic acid antagonists, pyrimidine analogs, purine analogs and adenosine deaminase inhibitors) such as methotrexate, 5-fluorouracil, floxuridine, cytarabine, 6-mercaptopurine, 6-thioguanine, fludarabine phosphate, pentostatine, and gemcitabine.

Suitable chemotherapeutic or other anti-cancer agents further include, for example, certain natural products and their derivatives (for example, vinca alkaloids, antitumor antibiotics, enzymes, lymphokines and epipodophyllotoxins) such as vinblastine, vincristine, vindesine, bleomycin, dactinomycin, daunorubicin, doxorubicin, epirubicin, idarubicin, ara-C, paclitaxel (TAXOL™), mithramycin, deoxycoformycin, mitomycin-C, L-asparaginase, interferons (especially IFN-a), etoposide, and teniposide.

Other cytotoxic agents include navelbene, CPT-11, anastrazole, letrazole, capecitabine, reloxafine, cyclophosphamide, ifosamide, and droloxafine.

Also suitable are cytotoxic agents such as epidophyllotoxin; an antineoplastic enzyme; a topoisomerase inhibitor; procarbazine; mitoxantrone; platinum coordination complexes such as cis-platin and carboplatin; biological response modifiers; growth inhibitors; antihormonal therapeutic agents; leucovorin; tegafur; and haematopoietic growth factors.

Other anti-cancer agent(s) include antibody therapeutics such as trastuzumab (Herceptin), antibodies to costimulatory molecules such as CTLA-4, 4-1BB, PD-L1 and PD-1 antibodies, or antibodies to cytokines (IL-10, TGF-β, etc.).

Other anti-cancer agents also include those that block immune cell migration such as antagonists to chemokine receptors, including CCR2 and CCR4.

Other anti-cancer agents also include those that augment the immune system such as adjuvants or adoptive T cell transfer.

Anti-cancer vaccines include dendritic cells, synthetic peptides, DNA vaccines and recombinant viruses. In some embodiments, tumor vaccines include the proteins from viruses implicated in human cancers such as Human Papilloma Viruses (HPV), Hepatitis Viruses (HBV and HCV) and Kaposi's Herpes Sarcoma Virus (KHSV). Non-limiting examples of tumor vaccines that can be used include peptides of melanoma antigens, such as peptides of gp100, MAGE antigens, Trp-2, MARTI and/or tyrosinase, or tumor cells transfected to express the cytokine GM-CSF.

The compounds of the present disclosure can be used in combination with bone marrow transplant for the treatment of a variety of tumors of hematopoietic origin.

Methods for the safe and effective administration of most of these chemotherapeutic agents are known to those skilled in the art. In addition, their administration is described in the standard literature. For example, the administration of many of the chemotherapeutic agents is described in the "Physicians' Desk Reference" (PDR, e.g., 1996 edition, Medical Economics Company, Montvale, NJ), the disclosure of which is incorporated herein by reference as if set forth in its entirety.

When more than one pharmaceutical agent is administered to a patient, they can be administered simultaneously, separately, sequentially, or in combination (*e.g.*, for more than two agents).

*Formulation, Dosage Forms and Administration*

When employed as pharmaceuticals, the compounds of the present disclosure can be administered in the form of pharmaceutical compositions. Thus the present disclosure

provides a composition comprising a compound of Formula (I) or any of the formulas as described herein, a compound as recited in any of the claims and described herein, or a pharmaceutically acceptable salt thereof, or any of the embodiments thereof, and at least one pharmaceutically acceptable carrier or excipient. The pharmaceutical compositions can comprise of a compound described herein and one or more second therapeutic agents as described herein. For example, the second therapeutic agent is a JAK inhibitor such as ruxolitinib. The compositions can be prepared in a manner well known in the pharmaceutical art, and can be administered by a variety of routes, depending upon whether local or systemic treatment is indicated and upon the area to be treated. Administration may be topical (including transdermal, epidermal, ophthalmic and to mucous membranes including intranasal, vaginal and rectal delivery), pulmonary (*e.g.*, by inhalation or insufflation of powders or aerosols, including by nebulizer; intratracheal or intranasal), oral or parenteral. Parenteral administration includes intravenous, intraarterial, subcutaneous, intraperitoneal intramuscular or injection or infusion; or intracranial, *e.g.*, intrathecal or intraventricular, administration. Parenteral administration can be in the form of a single bolus dose, or may be, *e.g.*, by a continuous perfusion pump. Pharmaceutical compositions and formulations for topical administration may include transdermal patches, ointments, lotions, creams, gels, drops, suppositories, sprays, liquids and powders. Conventional pharmaceutical carriers, aqueous, powder or oily bases, thickeners and the like may be necessary or desirable.

This invention also includes pharmaceutical compositions which contain, as the active ingredient, the compound of the present disclosure or a pharmaceutically acceptable salt thereof, in combination with one or more pharmaceutically acceptable carriers or excipients. In some embodiments, the composition is suitable for topical administration. In making the compositions of the present disclosure, the active ingredient is typically mixed with an excipient, diluted by an excipient or enclosed within such a carrier in the form of, *e.g.*, a capsule, sachet, paper, or other container. When the excipient serves as a diluent, it can be a solid, semi-solid, or liquid material, which acts as a vehicle, carrier or medium for the active ingredient. Thus, the compositions can be in the form of tablets, pills, powders, lozenges, sachets, cachets, elixirs, suspensions, emulsions, solutions, syrups, aerosols (as a solid or in a liquid medium), ointments containing, *e.g.*, up to 10% by weight of the active compound, soft and hard gelatin capsules, suppositories, sterile injectable solutions and sterile packaged powders.

In preparing a formulation, the active compound can be milled to provide the appropriate particle size prior to combining with the other ingredients. If the active

compound is substantially insoluble, it can be milled to a particle size of less than 200 mesh. If the active compound is substantially water soluble, the particle size can be adjusted by milling to provide a substantially uniform distribution in the formulation, *e.g.*, about 40 mesh.

The compounds of the present disclosure may be milled using known milling procedures such as wet milling to obtain a particle size appropriate for tablet formation and for other formulation types. Finely divided (nanoparticulate) preparations of the compounds of the present disclosure can be prepared by processes known in the art see, *e.g.*, WO 2002/000196.

In some embodiments, the composition is a sustained release composition comprising at least one compound described herein, or a pharmaceutically acceptable salt thereof, and at least one pharmaceutically acceptable carrier or excipient.

In some embodiments, a wet granulation process is used to produce the composition. In some embodiments, a dry granulation process is used to produce the composition.

The compositions can be formulated in a unit dosage form. The term "unit dosage forms" refers to physically discrete units suitable as unitary dosages for human subjects and other mammals, each unit containing a predetermined quantity of active material calculated to produce the desired therapeutic effect, in association with a suitable pharmaceutical excipient.

The components used to formulate the pharmaceutical compositions are of high purity and are substantially free of potentially harmful contaminants (*e.g.*, at least National Food grade, generally at least analytical grade, and more typically at least pharmaceutical grade). Particularly for human consumption, the composition is preferably manufactured or formulated under Good Manufacturing Practice standards as defined in the applicable regulations of the U.S. Food and Drug Administration. For example, suitable formulations may be sterile and/or substantially isotonic and/or in full compliance with all Good Manufacturing Practice regulations of the U.S. Food and Drug Administration.

The active compound may be effective over a wide dosage range and is generally administered in a therapeutically effective amount. It will be understood, however, that the amount of the compound actually administered will usually be determined by a physician, according to the relevant circumstances, including the condition to be treated, the chosen route of administration, the actual compound administered, the age, weight, and response of the individual patient, the severity of the patient's symptoms and the like.

For preparing solid compositions such as tablets, the principal active ingredient is mixed with a pharmaceutical excipient to form a solid preformulation composition containing a homogeneous mixture of a compound of the present invention. When referring to these preformulation compositions as homogeneous, the active ingredient is typically dispersed evenly throughout the composition so that the composition can be readily subdivided into equally effective unit dosage forms such as tablets, pills and capsules. This solid preformulation is then subdivided into unit dosage forms of the type described above containing from, *e.g.*, about 0.1 to about 1000 mg of the active ingredient of the present invention.

The tablets or pills of the present invention can be coated or otherwise compounded to provide a dosage form affording the advantage of prolonged action. For example, the tablet or pill can comprise an inner dosage and an outer dosage component, the latter being in the form of an envelope over the former. The two components can be separated by an enteric layer which serves to resist disintegration in the stomach and permit the inner component to pass intact into the duodenum or to be delayed in release. A variety of materials can be used for such enteric layers or coatings, such materials including a number of polymeric acids and mixtures of polymeric acids with such materials as shellac, cetyl alcohol and cellulose acetate.

The liquid forms in which the compounds and compositions of the present invention can be incorporated for administration orally or by injection include aqueous solutions, suitably flavored syrups, aqueous or oil suspensions, and flavored emulsions with edible oils such as cottonseed oil, sesame oil, coconut oil, or peanut oil, as well as elixirs and similar pharmaceutical vehicles.

Compositions for inhalation or insufflation include solutions and suspensions in pharmaceutically acceptable, aqueous or organic solvents, or mixtures thereof, and powders. The liquid or solid compositions may contain suitable pharmaceutically acceptable excipients as described *supra*. In some embodiments, the compositions are administered by the oral or nasal respiratory route for local or systemic effect. Compositions can be nebulized by use of inert gases. Nebulized solutions may be breathed directly from the nebulizing device or the nebulizing device can be attached to a face mask, tent, or intermittent positive pressure breathing machine. Solution, suspension, or powder compositions can be administered orally or nasally from devices which deliver the formulation in an appropriate manner.

Topical formulations can contain one or more conventional carriers. In some embodiments, ointments can contain water and one or more hydrophobic carriers selected

from, *e.g.*, liquid paraffin, polyoxyethylene alkyl ether, propylene glycol, white Vaseline, and the like. Carrier compositions of creams can be based on water in combination with glycerol and one or more other components, *e.g.*, glycerinemonostearate, PEG-glycerinemonostearate and cetylstearyl alcohol. Gels can be formulated using isopropyl alcohol and water, suitably in combination with other components such as, *e.g.*, glycerol, hydroxyethyl cellulose, and the like.

The amount of compound or composition administered to a patient will vary depending upon what is being administered, the purpose of the administration, such as prophylaxis or therapy, the state of the patient, the manner of administration and the like. In therapeutic applications, compositions can be administered to a patient already suffering from a disease in an amount sufficient to cure or at least partially arrest the symptoms of the disease and its complications. Effective doses will depend on the disease condition being treated as well as by the judgment of the attending clinician depending upon factors such as the severity of the disease, the age, weight and general condition of the patient and the like.

The compositions administered to a patient can be in the form of pharmaceutical compositions described above. These compositions can be sterilized by conventional sterilization techniques, or may be sterile filtered. Aqueous solutions can be packaged for use as is, or lyophilized, the lyophilized preparation being combined with a sterile aqueous carrier prior to administration.

The therapeutic dosage of a compound of the present invention can vary according to, *e.g.*, the particular use for which the treatment is made, the manner of administration of the compound, the health and condition of the patient, and the judgment of the prescribing physician. The proportion or concentration of a compound of the present disclosure in a pharmaceutical composition can vary depending upon a number of factors including dosage, chemical characteristics (*e.g.*, hydrophobicity), and the route of administration. The dosage is likely to depend on such variables as the type and extent of progression of the disease or disorder, the overall health status of the particular patient, the relative biological efficacy of the compound selected, formulation of the excipient, and its route of administration. Effective doses can be extrapolated from dose-response curves derived from *in vitro* or animal model test systems.

*Labeled Compounds and Assay Methods*

The compounds of the present disclosure can further be useful in investigations of biological processes in normal and abnormal tissues. Thus, another aspect of the present

invention relates to fluorescent dye, spin label, heavy metal or radio-labeled compounds provided herein that would be useful not only in imaging techniques but also in assays, both *in vitro* and *in vivo*, for localizing and quantitating ALK2 protein in tissue samples, including human, and for identifying ALK2 ligands by inhibition binding of a labeled compound. Accordingly, the present invention includes ALK2 binding assays that contain such labeled compounds.

The present invention further includes isotopically-substituted compounds of the disclosure. An "isotopically-substituted" compound is a compound of the present disclosure where one or more atoms are replaced or substituted by an atom having the same atomic number but a different atomic mass or mass number. Compounds of the present disclosure may contain isotopes in a natural abundance as found in nature. Compounds of the present disclosure may also have isotopes in amounts greater to that found in nature, e.g., synthetically incorporating low natural abundance isotopes into the compounds of the present disclosure so they are enriched in a particularly useful isotope (e.g., $^{2}H$ and $^{13}C$). It is to be understood that a "radio-labeled" compound is a compound that has incorporated at least one isotope that is radioactive (e.g., radionuclide), e.g., $^{3}H$ and $^{14}C$. Suitable radionuclides that may be incorporated in compounds of the present invention include but are not limited to $^{3}H$ (also written as T for tritium), $^{11}C$, $^{13}C$, $^{14}C$, $^{13}N$, $^{15}N$, $^{15}O$, $^{17}O$, $^{18}O$, $^{18}F$, $^{35}S$, $^{36}Cl$, $^{82}Br$, $^{75}Br$, $^{76}Br$, $^{77}Br$, $^{123}I$, $^{124}I$, $^{125}I$ and $^{131}I$. The radionuclide that is incorporated in the instant radio-labeled compounds will depend on the specific application of that radio-labeled compound. In some embodiments, the radionuclide is selected from the group consisting of $^{3}H$, $^{14}C$, $^{125}I$, $^{35}S$ and $^{82}Br$. For *in vitro* ALK2 labeling and competition assays, compounds that incorporate $^{3}H$, $^{14}C$, $^{82}Br$, $^{125}I$, $^{131}I$, or $^{35}S$ will generally be most useful. For radio-imaging applications $^{11}C$, $^{18}F$, $^{125}I$, $^{123}I$, $^{124}I$, $^{131}I$, $^{75}Br$, $^{76}Br$ or $^{77}Br$ will generally be most useful. The present disclosure can further include synthetic methods for incorporating radio-isotopes into compounds of the disclosure. Synthetic methods for incorporating radio-isotopes into organic compounds are well known in the art and a person of ordinary skill in the art will readily recognize the methods applicable for the compounds of disclosure.

One or more constituent atoms of the compounds presented herein can be replaced or substituted with isotopes of the atoms in natural or non-natural abundance. In some embodiments, the compound includes at least one deuterium atom. In some embodiments, the compound includes two or more deuterium atoms. In some embodiments, the compound includes 1-2, 1-3, 1-4, 1-5, or 1-6 deuterium atoms. In some embodiments, all of the hydrogen atoms in a compound can be replaced or substituted by deuterium atoms.

Synthetic methods for including isotopes into organic compounds are known in the art (Deuterium Labeling in Organic Chemistry by Alan F. Thomas (New York, N.Y., Appleton-Century-Crofts, 1971; The Renaissance of H/D Exchange by Jens Atzrodt, Volker Derdau, Thorsten Fey and Jochen Zimmermann, Angew. Chem. Int. Ed. 2007, 7744-7765; The Organic Chemistry of Isotopic Labelling by James R. Hanson, Royal Society of Chemistry, 2011). Isotopically labeled compounds can be used in various studies such as NMR spectroscopy, metabolism experiments, and/or assays.

Substitution with heavier isotopes, such as deuterium, may afford certain therapeutic advantages resulting from greater metabolic stability, for example, increased *in vivo* half-life or reduced dosage requirements, and hence may be preferred in some circumstances. (see *e.g.*, A. Kerekes et. al. J. *Med. Chem.* 2011, 54, 201-210; R. Xu et. al. J. *Label Compd. Radiopharm.* 2015, 58, 308-312). In particular, substitution at one or more metabolism sites may afford one or more of the therapeutic advantages. Specifically, a labeled compound of the present disclosure can be used in a screening assay to identify and/or evaluate compounds. For example, a newly synthesized or identified compound (*i.e.*, test compound) which is labeled can be evaluated for its ability to bind a ALK2 protein by monitoring its concentration variation when contacting with the ALK2, through tracking of the labeling. For example, a test compound (labeled) can be evaluated for its ability to reduce binding of another compound which is known to bind to a ALK2 protein (*i.e.*, standard compound). Accordingly, the ability of a test compound to compete with the standard compound for binding to the ALK2 protein directly correlates to its binding affinity. Conversely, in some other screening assays, the standard compound is labeled and test compounds are unlabeled. Accordingly, the concentration of the labeled standard compound is monitored in order to evaluate the competition between the standard compound and the test compound, and the relative binding affinity of the test compound is thus ascertained.

*Kits*

The present disclosure also includes pharmaceutical kits useful, *e.g.*, in the treatment or prevention of diseases or disorders associated with the activity of ALK2, such as cancer or infections, which include one or more containers containing a pharmaceutical composition comprising a therapeutically effective amount of a compound of Formula I, or any of the embodiments thereof. Such kits can further include one or more of various conventional pharmaceutical kit components, such as, *e.g.*, containers with one or more pharmaceutically acceptable carriers, additional containers, *etc.*, as will be readily apparent to those skilled in

the art. Instructions, either as inserts or as labels, indicating quantities of the components to be administered, guidelines for administration, and/or guidelines for mixing the components, can also be included in the kit.

The invention will be described in greater detail by way of specific examples. The following examples are offered for illustrative purposes, and are not intended to limit the invention in any manner. Those of skill in the art will readily recognize a variety of non-critical parameters which can be changed or modified to yield essentially the same results. The compounds of the Examples have been found to inhibit the activity of ALK2 according to at least one assay described herein.

## EXAMPLES

Experimental procedures for compounds of the present disclosure are provided below. Preparatory LC-MS purifications of some of the compounds prepared were performed on Waters mass directed fractionation systems. The basic equipment setup, protocols, and control software for the operation of these systems have been described in detail in the literature. See e.g. "Two-Pump At Column Dilution Configuration for Preparative LC-MS", K. Blom, *J. Combi. Chem.*, 4, 295 (**2002**); "Optimizing Preparative LC-MS Configurations and Methods for Parallel Synthesis Purification", K. Blom, R. Sparks, J. Doughty, G. Everlof, T. Haque, A. Combs, *J. Combi. Chem.*, 5, 670 (**2003**); and "Preparative LC-MS Purification: Improved Compound Specific Method Optimization", K. Blom, B. Glass, R. Sparks, A. Combs, *J. Combi. Chem.*, 6, 874-883 (**2004**). The compounds separated were typically subjected to analytical liquid chromatography mass spectrometry (LCMS) for purity check under the following conditions: Instrument; Agilent 1100 series, LC/MSD, Column: Waters Sunfire™ $C_{18}$ 5 μm particle size, 2.1 x 5.0 mm, Buffers: mobile phase A: 0.025% TFA in water and mobile phase B: acetonitrile; gradient 2% to 80% of B in 3 minutes with flow rate 2.0 mL/minute.

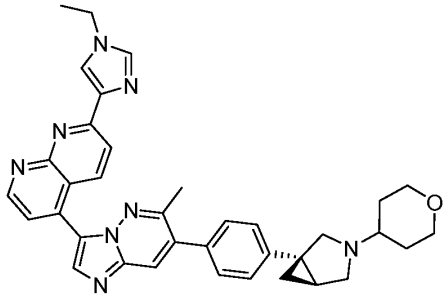
Some of the compounds prepared were also separated on a preparative scale by reverse-phase high performance liquid chromatography (RP-HPLC) with MS detector or flash chromatography (silica gel) as indicated in the Examples. Typical preparative reverse-phase high performance liquid chromatography (RP-HPLC) column conditions are as follows:

pH = 2 purifications: Waters Sunfire™ $C_{18}$ 5 μm particle size, 30 x 100 mm column, eluting with mobile phase A: 0.1% TFA (trifluoroacetic acid) in water and mobile phase B: acetonitrile; the flow rate was 60 mL/minute, the separating gradient was optimized for each

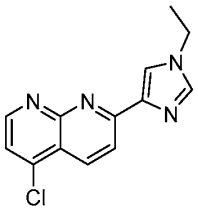
compound using the Compound Specific Method Optimization protocol as described in the literature [see "Preparative LCMS Purification: Improved Compound Specific Method Optimization", K. Blom, B. Glass, R. Sparks, A. Combs, *J. Comb. Chem.*, **6**, 874-883 (2004)].

pH = 10 purifications: Waters XBridge $C_{18}$ 5 μm particle size, 30 x 100 mm column, eluting with mobile phase A: 0.15% $NH_4OH$ in water and mobile phase B: acetonitrile; the flow rate was 60 mL/minute, the separating gradient was optimized for each compound using the Compound Specific Method Optimization protocol as described in the literature [See "Preparative LCMS Purification: Improved Compound Specific Method Optimization", K. Blom, B. Glass, R. Sparks, A. Combs, *J. Comb. Chem.*, **6**, 874-883 (2004)].

**Example 1. 2-(1-Ethyl-1H-imidazol-4-yl)-5-(6-methyl-7-(4-((1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine**



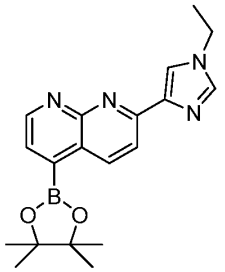
*Step 1: 5-Chloro-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine*



To a screw-cap vial equipped with a magnetic stir bar was added 2,5-dichloro-1,8-naphthyridine (956.8 mg, 4.81 mmol), 1-ethyl-4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1H-imidazole (1048 mg, 4.72 mmol), tetrakis(triphenylphosphine)palladium(0) (1117 mg, 0.966 mmol) and cesium carbonate (4788 mg, 14.70 mmol). The vial was sealed with a Teflon-lined septum, evacuated and backfilled with nitrogen (this process was repeated a total of three times). 1,4-Dioxane (20.0 mL) was added via syringe, followed by water (3.0 mL). The mixture was stirred at 70 °C for 6 h. After cooling at room temperature, the mixture

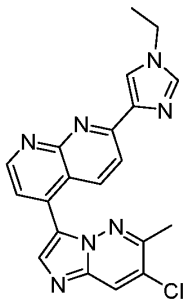
was concentrated. The residue was purified on silica gel (40 g, 0-100% EtOAc in $CH_2Cl_2$, then 15% MeOH in $CH_2Cl_2$) to give the desired product as a yellow solid (394.2 mg, 32%). LCMS calculated for $C_{13}H_{12}ClN_4$ $(M+H)^+$ m/z = 259.1; found 259.1.

*Step 2: 2-(1-Ethyl-1H-imidazol-4-yl)-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,8-naphthyridine*



To a screw-cap vial equipped with a magnetic stir bar was added 4,4,5,5,4',4',5',5'-octamethyl-[2,2']bi[[1,3,2]dioxaborolanyl] (515.0 mg, 2.028 mmol), potassium acetate (496.8 mg, 5.06 mmol), 5-chloro-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine (394.2 mg, 1.524 mmol) and dichloro[1,1'-bis(diphenylphosphino)ferrocene]palladium (II) dichloromethane adduct (258 mg, 0.315 mmol). The vial was sealed with a Teflon-lined septum, evacuated and backfilled with nitrogen (this process was repeated a total of three times). 1,4-Dioxane (12.0 mL) was added via syringe. The mixture was stirred at 105 °C for 16 h. After cooling at room temperature, the mixture was filtered. The filtrate was used directly in the next step without further purification. LCMS calculated for $C_{19}H_{24}BN_4O_2$ $(M+H)^+$ m/z = 351.2; found 351.2.

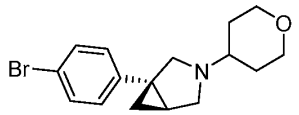
*Step 3: 5-(7-Chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine*



To a screw-cap vial equipped with a magnetic stir bar was added 7-chloro-3-iodo-6-methylimidazo[1,2-b]pyridazine (497.4 mg, 1.695 mmol), dichloro[1,1'-

bis(diphenylphosphino)ferrocene]palladium (II) dichloromethane adduct (253 mg, 0.310 mmol) and cesium carbonate (1987 mg, 6.10 mmol). The vial was sealed with a Teflon-lined septum, evacuated and backfilled with nitrogen (this process was repeated a total of three times). A solution of 2-(1-ethyl-1H-imidazol-4-yl)-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,8-naphthyridine (534 mg, 1.525 mmol, see above step 2) in 1,4-dioxane (12.0 mL) was added via syringe followed by water (3.0 mL). The mixture was stirred at 80 °C for 16 h. After cooling to room temperature, the reaction mixture was concentrated. The residue was purified on silica gel (40 g, 0-100% EtOAc in $CH_2Cl_2$, then 0-15% MeOH in $CH_2Cl_2$) to give the desired product as a solid (341.3 mg, 57%). LCMS calculated for $C_{20}H_{17}ClN_7$ $(M+H)^+$ m/z = 390.1; found 390.1.

*Step 4: (1R,5S)-1-(4-bromophenyl)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexane*




To a solution of (1R,5S)-1-(4-bromophenyl)-3-azabicyclo[3.1.0]hexane (354.4 mg, 1.488 mmol, Affinity Research Chemicals) in dichoroethane (20.0 mL) was added sodium triacetoxyborohydride (534.7 mg, 2.52 mmol) and acetic acid (330 µL, 5.76 mmol) followed by tetrahydro-4H-pyran-4-one (318.6 mg, 3.18 mmol). The mixture was stirred at room temperature for 16 h. The reaction mixture was washed with 2M $K_2CO_3$ (aq). The separated organic layer was dried over anhydrous $Na_2SO_4$, filtered and concentrated. The residue was purified on silica gel (20 g, 0-100% EtOAc in DCM) to give the desired product as a colorless oil (398.3 mg, 83%). LCMS calculated for $C_{16}H_{21}BrNO$ $(M+H)+$ m/z = 322.1; found 322.1.

*Step 5: (1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-3-azabicyclo[3.1.0]hexane*



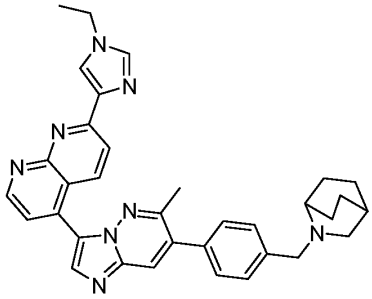

To a screw-cap vial equipped with a magnetic stir bar was added 4,4,5,5,4',4',5',5'-octamethyl-[2,2']bi[[1,3,2]dioxaborolanyl] (318.8 mg, 1.255 mmol), potassium acetate (316.6 mg, 3.23 mmol), (*1R,5S*)-1-(4-bromophenyl)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexane (298.7 mg, 0.927 mmol) and dichloro[1,1'-

bis(diphenylphosphino)ferrocene]palladium (II) dichloromethane adduct (115.1 mg, 0.141 mmol). The vial was sealed with a Teflon-lined septum, evacuated and backfilled with nitrogen (this process was repeated a total of three times). 1,4-Dioxane (12.0 mL) was added via syringe. The mixture was stirred at 105 °C for 16 h. After cooling at room temperature, the mixture was filtered. The filtrate was used directly in the next step without further purification. LCMS calculated for $C_{22}H_{33}BNO_3$ (M+H)+ m/z = 370.3; found 370.2.

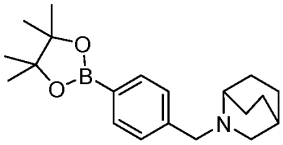
*Step 6: 2-(1-Ethyl-1H-imidazol-4-yl)-5-(6-methyl-7-(4-((1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine*

To a screw-cap vial equipped with a magnetic stir bar was added 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine (277.2 mg, 0.711 mmol), (1R,5S)-3-(tetrahydro-2H-pyran-4-yl)-1-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)phenyl)-3-azabicyclo[3.1.0]hexane (342 mg, 0.926 mmol), dicyclohexyl(2',4',6'-triisopropylbiphenyl-2-yl)phosphine - (2'-aminobiphenyl-2-yl)(chloro)palladium (1:1) (XPhos Pd G2, 84 mg, 0.107 mmol) and cesium carbonate (846.7 mg, 2.60 mmol). The vial was sealed with a Teflon-lined septum, evacuated and backfilled with nitrogen (this process was repeated a total of three times). 1,4-Dioxane (20.0 mL) was added via syringe, followed by water (2.0 mL). The mixture was heated at 80 ºC for 6 h. After cooling to room temperature, the reaction was diluted with MeOH and purified using prep-LCMS (XBridge C18 column, eluting with a gradient of acetonitrile/water containing 0.1% TFA, at flow rate of 60 mL/min) to afford the desired product as its TFA salt. LCMS calculated for $C_{36}H_{37}N_8O$ $(M+H)^+$: m/z = 597.3; found: 597.3. $^1$H NMR (500 MHz, DMSO-$d_6$) δ 9.78 (s, 1H), 9.27 (d, *J* = 4.7 Hz, 1H), 8.90 (s, 1H), 8.63 (overlap, 2H), 8.32 (s, 1H), 8.20 (d, *J* = 8.7 Hz, 1H), 8.15 (s, 1H), 8.07 (d, *J* = 4.7 Hz, 1H), 7.57 (d, *J* = 8.4 Hz, 2H), 7.47 (d, *J* = 8.4 Hz, 2H), 4.26 (q, *J* = 7.3 Hz, 2H), 4.11 (m, 1H), 3.98 (m, 2H), 3.77 (overlap, 2H), 3.62 (m, 1H), 3.48 (m, 1H), 3.27 (m, 2H), 2.40 (s, 3H), 2.34 (m, 1H), 2.03 (dd, *J* = 48.7, 12.3 Hz, 2H), 1.69 (m, 2H), 1.51 (t, *J* = 7.3 Hz, 3H), 1.42 (m, 1H), 1.25 (m, 1H).

**Example 2. 2-(4-(3-(7-(1-Ethyl-1H-imidazol-4-yl)-1,8-naphthyridin-4-yl)-6-methylimidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane**



*Step 1: 2-(4-(4,4,5,5-Tetramethyl-1,3,2-dioxaborolan-2-yl)benzyl)-2-azabicyclo[2.2.2]octane*



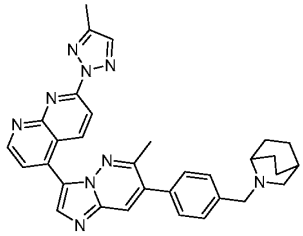
To a mixture of 2-(4-(bromomethyl)phenyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane (304.1 mg, 1.024 mmol), $Cs_2CO_3$ (1060.2 mg, 3.25 mmol) and 2-azabicyclo[2.2.2]octane (161.8 mg, 1.455 mmol) was added 1,4-dioxane (10.0 mL). The mixture was stirred at 80 °C for 1 h. After cooling to room temperature, the reaction mixture was filtered. The filtrate was used directly in the next step without further purification. LCMS calculated for $C_{20}H_{31}BNO_2$ (M+H)+ m/z = 328.2; found 328.2.

*Step 2: 2-(4-(3-(7-(1-Ethyl-1H-imidazol-4-yl)-1,8-naphthyridin-4-yl)-6-methylimidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane*

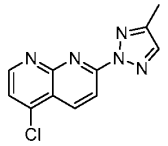
To a screw-cap vial equipped with a magnetic stir bar was added 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine (257.9 mg, 0.662 mmol), dicyclohexyl(2',4',6'-triisopropylbiphenyl-2-yl)phosphine - (2'-aminobiphenyl-2-yl)(chloro)palladium (1:1) (XPhos Pd G2, 78.1 mg, 0.099 mmol), and cesium carbonate (780.0 mg, 2.394 mmol). The vial was sealed with a Teflon-lined septum, evacuated, and backfilled with nitrogen (this process was repeated a total of three times). A solution of 2-(4-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)benzyl)-2-azabicyclo[2.2.2]octane (335 mg, 1.024 mmol) in 1,4-dioxane (20.0 mL) was added, followed by degassed water (2.0 mL, 111 mmol). The mixture was heated at 80 °C for 6 h. After cooling to room temperature, the reaction was diluted with MeOH and purified using prep-LCMS (XBridge C18 column, eluting with a gradient of acetonitrile/water containing 0.1% TFA, at flow rate of 60 mL/min) to afford the desired product as its TFA salt. LCMS

calculated for $C_{34}H_{35}N_8$ $(M+H)^+$: m/z = 555.3; found: 555.3. $^1H$ NMR (600 MHz, DMSO-$d_6$) δ 9.41 (br, 1H), 9.26 (d, $J$ = 4.6 Hz, 1H), 8.78 (br, 1H), 8.61 (d, $J$ = 8.7 Hz, 1H), 8.56 (s, 1H), 8.32 (s, 1H), 8.20 (overlap, 2H), 8.05 (d, $J$ = 4.6 Hz, 1H), 7.75 (d, $J$ = 8.0 Hz, 2H), 7.68 (d, $J$ = 8.0 Hz, 2H), 4.48 (m, 2H), 4.24 (q, $J$ = 7.3 Hz, 2H), 3.35 (m, 1H), 3.30 (m, 1H), 3.08 (m, 1H), 2.42 (s, 3H), 2.31 (m, 1H), 2.02 (m, 1H), 1.95 (m, 1H), 1.82 (m, 1H), 1.79 – 1.57 (overlap, 5H), 1.50 (t, $J$ = 7.3 Hz, 3H).

**Example 3. 2-(4-(6-Methyl-3-(7-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridin-4-yl)imidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane**

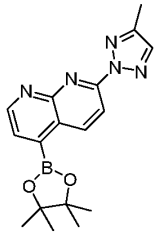


*Step 1: 5-Chloro-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine*



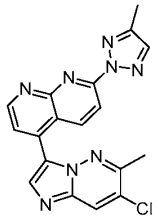
To a 100 mL round bottom flask equipped with a magnetic stir bar was charged 4-methyl-2H-1,2,3-triazole (ENAMINE, 1 g, 12.03 mmol), $Cs_2CO_3$ (7.82 g, 24.07 mmol), and 5-chloro-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine (1.61 g, 6.55 mmol, 54.5 % yield). To this flask was added 60 mL acetonitrile. The flask was sealed with a rubber septum and 65 mL acetonitrile was added. The mixture was stirred at room temperature for 16 h. The resulting solution was diluted with $CH_2Cl_2$ (100 mL), and filtered through Celite and then concentrated. The residue was purified on silica gel (50 g, 0-100% EtOAc in $CH_2Cl_2$) to give the desired product as yellow foamy solid (1.61 g, 55% yield). LCMS calculated for $C_{11}H_9ClN_5$ $(M+H)^+$ m/z = 246.1; found 246.1.

*Step 2: 2-(4-Methyl-2H-1,2,3-triazol-2-yl)-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,8-naphthyridine*



A 100 mL round bottom flask was charged with a mixture of 5-chloro-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine (1.61 g, 6.55 mmol), potassium acetate (1.286 g, 13.11 mmol), bis(pinacolato)diboron (2.496 g, 9.83 mmol), and $Pd(dppf)Cl_2$.DCM (0.532 g, 0.655 mmol). The flask was sealed, evacuated, and backfilled with nitrogen (this process was repeated a total of three times). To this flask was added 60 mL of degassed 1,4-Dioxane. The mixture was heated to 100 °C for 16 h. The resulting mixture was cooled down to room temperature and diluted with 100 mL DCM, and then filtered through Celite. The filtrate was then concentrated to give the crude product, which was used directly in the next step without further purification. LCMS calculated for $C_{17}H_{21}BN_5O_2$ $(M+H)^+$: m/z = 338.2; found: 338.1.

*Step 3: 5-(7-Chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine*

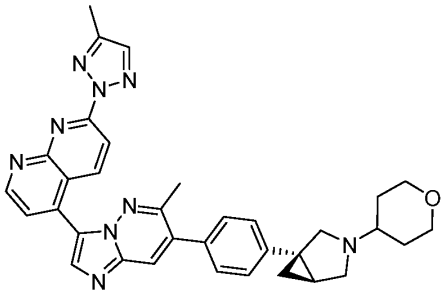


A 100 mL round bottom flask equipped with a magnetic stir bar and was charged with 2-(4-methyl-2H-1,2,3-triazol-2-yl)-5-(4,4,5,5-tetramethyl-1,3,2-dioxaborolan-2-yl)-1,8-naphthyridine (1.608 g, 4.77 mmol), 7-chloro-3-iodo-6-methylimidazo[1,2-b]pyridazine (1 g, 3.41 mmol), $Pd(dppf)Cl_2$·DCM (0.692 g, 0.852 mmol), and $Cs_2CO_3$ (3.88 g, 11.93 mmol). The flask was sealed, evacuated, and backfilled with nitrogen (this process was repeated a total of three times). To this flask was added 40 mL degassed 1,4-dioxane and 10 mL degassed water. The mixture was heated to 80 °C for 3 h. The resulting mixture was cooled down to room temperature and diluted with DCM, and then filtered through celite and concentrated. The residue was purified on silica gel (50 g, 0-100% EtOAc in $CH_2Cl_2$, then , 0-15% MeOH in $CH_2Cl_2$ ) to give the desired product as a brown solid (0.68 g, 53%). LCMS calculated for $C_{18}H_{14}ClN_8$ $(M+H)^+$: m/z = 377.1; found: 377.1.

*Step 4: 2-(4-(6-Methyl-3-(7-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridin-4-yl)imidazo[1,2-b]pyridazin-7-yl)benzyl)-2-azabicyclo[2.2.2]octane*

This compound was prepared according to the procedure described in Example 2, Step 6 using 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine instead of 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine as the starting material. LCMS calculated for $C_{32}H_{32}N_9$ $(M+H)^+$: m/z = 542.3; found: 542.4. $^1H$ NMR (TFA salt, 600 MHz, DMSO-$d_6$) δ 9.53 (s, 1H), 9.29 (d, *J* = 4.5 Hz, 1H), 8.70 (d, *J* = 9.0 Hz, 1H), 8.36 – 8.28 (m, 2H), 8.20 (s, 1H), 8.14 (s, 1H), 8.07 (d, *J* = 4.6 Hz, 1H), 7.76 (d, *J* = 8.1 Hz, 2H), 7.69 (d, *J* = 8.1 Hz, 2H), 4.55-4.50 (m, 1H), 4.46 (dd, *J* = 13.0, 5.4 Hz, 1H), 3.38-3.29 (m, 2H), 3.09 (dd, *J* = 11.7, 4.7 Hz, 1H), 2.46 (s, 3H), 2.42 (s, 3H), 2.32 (brs, 1H), 2.07 – 1.99 (m, 1H), 1.95 (s, 1H), 1.84 (t, *J* = 11.3 Hz, 1H), 1.79-1.58 (m, 5H).

**Example 4. 2-(4-Methyl-2H-1,2,3-triazol-2-yl)-5-(6-methyl-7-(4-((1S,5R)-3-(tetrahydro-2H-pyran-4-yl)-3-azabicyclo[3.1.0]hexan-1-yl)phenyl)imidazo[1,2-b]pyridazin-3-yl)-1,8-naphthyridine**



This compound was prepared according to the procedure described in Example 1 (step 6), using 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(4-methyl-2H-1,2,3-triazol-2-yl)-1,8-naphthyridine instead of 5-(7-chloro-6-methylimidazo[1,2-b]pyridazin-3-yl)-2-(1-ethyl-1H-imidazol-4-yl)-1,8-naphthyridine as the starting material. LCMS calculated for $C_{34}H_{34}N_9O$ $(M+H)^+$: m/z = 584.3; found: 584.3.

**Example A. ALK2 HTRF Assay**

ALK2 (aa 147-end) was obtained from BPS biosciences. The enzymatic assays were conducted in white 384-well polystyrene plates in a final volume of 8 μL. The inhibitors were serially diluted in DMSO and added to the plate wells prior to addition of the other reaction components. The assays were carried out at 25 °C in the assay buffer (50 mM HEPES, pH 7.0, 10% Glycerol, 0.01% Brij50, 10 mM $MgCl_2$, 1 mM EGTA, 5 mM DTT, and 0.01% BSA), containing 50 nM LANCE Ultra ULight™-DNA Topoisomerase 2-alpha peptide (Perkin Elmer TRF0130), and 3 μM ATP. The final concentration of DMSO in the assay was 1% and the enzyme concentration was 0.5 nM for ALK2. The reactions were allowed to proceed for 2 hr for ALK2 after which, the reaction was quenched by addition of EDTA at a final concentration of 20 mM along with 1.5 nM LANCE Ultra Europium-anti-phospho-DNA Topoisomerase 2-alpha (Thr1342) antibody (Perkin Elmer TRF0218). The reaction was incubated at 25 °C for 1 hr and read on a PHERAstar FS plate reader (BMG Labtech). $IC_{50}$ determination was performed by fitting percent control activity versus the log of the inhibitor concentration using the IDBS XLFit and GraphPad Prism 5.0 software.

Compounds of the present disclosure, as exemplified in Examples, showed the $IC_{50}$ values in the following ranges: + = $IC_{50} \leq 1$ nM; ++ = 1 nM < $IC_{50} \leq 5$ nM; +++ = 5 nM < $IC_{50} \leq 100$ nM, ++++ = $IC_{50} > 100$ nM.

Table 1

| Example # | ALK2 $IC_{50}$ (nM) |
|---|---|
| 1 | + |
| 2 | + |
| 3 | + |
| 4 | + |

Various modifications of the present disclosure, in addition to those described herein, will be apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims. Each reference, including without limitation all patent, patent applications, and publications, cited in the present application is incorporated herein by reference in its entirety.